Delta Smelt and CALFED's Environmental Water Account: A Summary of the 2002 Delta Smelt Workshop

By

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CALFED Science Program
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Acknowledgments

We would like to thank presenters at the 2002 delta smelt workshop for providing their PowerPoint slides for use in this paper. We regret that the deadline for submitting material to the EWA review panel limited time for all presenters to review the report. We do thank Kevin Fleming, Joe Cech, Joan Lindberg, and Bradd Baskerville-Bridges for their comments.

Introduction

On September 4, 2002 the CALFED Bay-Delta Program (CALFED) sponsored the second annual delta smelt Environmental Water Account (EWA) workshop. The agenda and list of attendees are appendices A and B, respectively. The workshop presenters developed the agenda (page 38). Because the Interagency Ecological Program (IEP) will be sponsoring an abundance/population index workshop in November 2002, to include delta smelt, this EWA workshop did not include any interpretive data analysis.

The workshop objectives were described in the workshop announcement as follows:

The purpose of this workshop is to publicly describe and discuss a proposed strategy for delta smelt research with the intent of receiving ample and direct comments from all attendees. These discussions and comments will be used to develop a final research strategy that the IEP and the CALFED Science Program can use to guide delta smelt research over the next three years. This workshop and resulting research strategy directly address the 2001 EWA review panel recommendation "develop a research strategy for delta smelt"

The workshop presentations were designed to focus on different aspects of the proposed research plan.

In this report we generally summarize the presentations made at the workshop, with the caveat that we only include highlights of the presentations. We take responsibility for omissions, emphasis and interpretation of the presentations. We also include some information in the appendices not found in the presentations. This inclusion is to help the intended audience, the EWA review panel and others not working directly on delta smelt research in the San Francisco Estuary, to better understand the material.

Although the workshop was focused on a delta smelt research strategy, and the attendees (page 39) had copies of the draft strategy, the details of the strategy did not appear in any of the presentations. We have attached the draft strategy (Appendix C) to provide more detail as to where IEP expects to be going over the next few years. In an effort to increase the EWA Review Panel's access to new ideas about delta smelt, we have also attached a draft delta smelt research strategy developed by Warren Shaul of Jones and Stokes Associates (Appendix D). This material was handed out at the workshop but not discussed and the proposal has not been reviewed by the delta smelt study team.

We do assume some familiarity with the San Francisco Estuary and operation of the state and federal water projects and provided considerable background material in three 2001 papers (Brown and Kimmerer 2001a, b, c). These reports can be found at http://www.calfed.ca.gov along with the 2001 report by the EWA review panel.

CALFED sponsored the 2001 delta smelt and salmonid workshops (see Brown and Kimmerer 2002a on the CALFED website for a summary of the 2002 salmonid workshop) in direct response to the Environmental Water Account - a CALFED program that acquires and stores water benefit sensitive fish species (delta smelt, Chinook salmon, Sacramento splittail and green sturgeon) that live in or move through the Sacramento-San Joaquin Delta (Figure 1). These fish are all listed or candidate species pursuant to either the State or federal endangered species act. Use of EWA water is to provide protection for endangered and threatened fish species while minimizing loss of water supplies to the State and federal water projects that divert water from the Sacramento-San Joaquin Delta for use by farmers and municipalities in Central and Southern California.

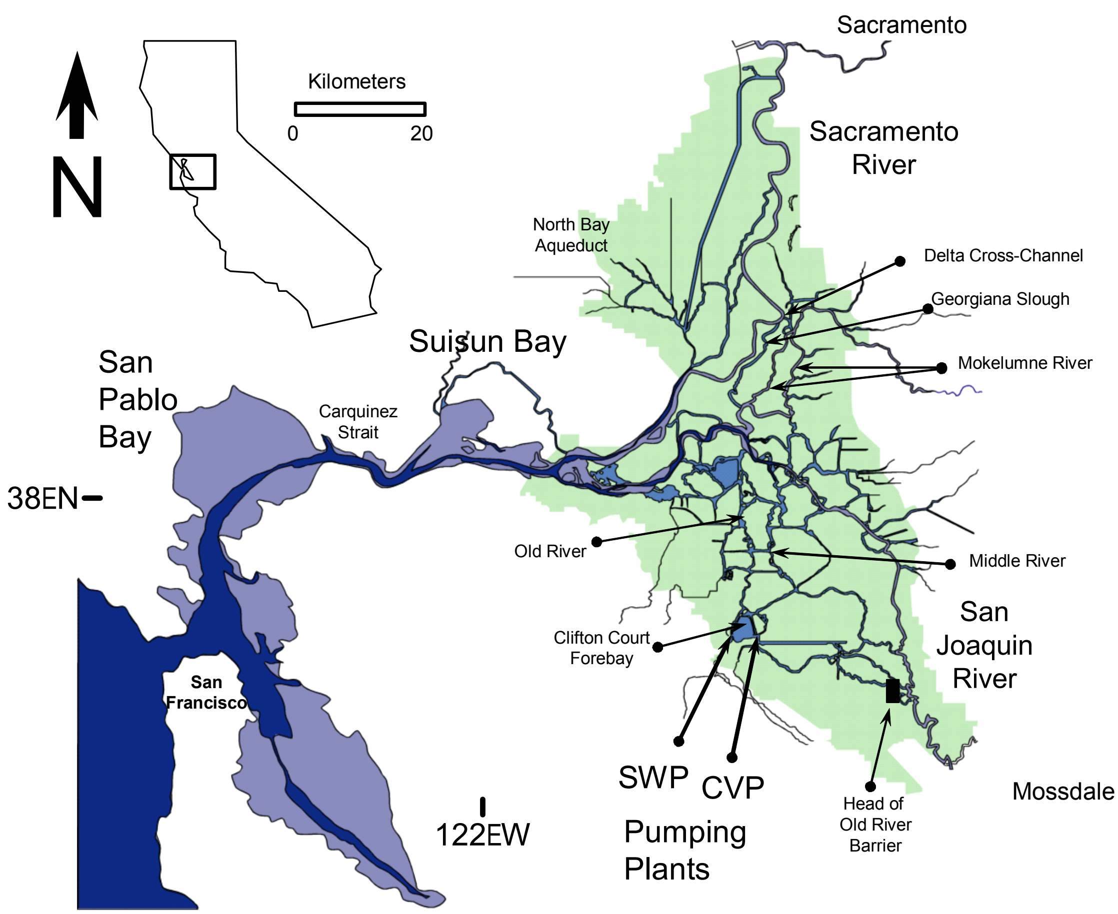


Figure 1 Map of northern reaches of San Francisco Estuary

As you will discover, the workshop organizers decided not to include a presentation summarizing 2002 EWA actions taken to protect delta smelt - in part due to the minimal use of EWA assets to protect smelt (take at the pumps was general low) and in part due to lack of time in a one-day workshop. The US Fish and Wildlife Service staff has prepared a separate analysis of EWA actions and their report was submitted directly to Sam Luoma and the EWA review panel.

The report is organized by presentation in the same sequence as shown in the agenda. Note that the final agenda was not the same as shown in the notice announcing the program. We used the titles of the presentations from the speakers' PowerPoint slides - not from the published agenda.

IEP Delta Smelt Research Strategy

Bruce Herbold (USEPA) described the approach used by IEP to develop the draft comprehensive research strategy described in Appendix C. The strategy is to help answer the following questions related to delta smelt management.

1). What controls the abundance and distribution of delta smelt?

2). What factors threaten their continued existence?

3). What are the benefits of habitat restoration, flow manipulation and fish screening improvements for this species?

The strategy proceeds in three steps.

1). Describe the conceptual models pertaining to each aspect of factors of delta smelt biology that relate to management issues.

2). Describe research themes arising from the conceptual models.

3). Describe the interconnections among the various factors and potential areas of synergy among the research efforts.

The strategy is based largely on the draft CALFED white paper, the delta smelt decision tree (see Brown and Kimmerer 2001b) documents developed through a CALFED sponsored Comprehensive Monitoring, Assessment and Research Plan (CMARP), several research proposals (and reviewers' comments) submitted to CALFED as part of 2002 RFP and discussion among delta smelt biologists held between December 2001 and June 2002.

The research proposal will become part of the IEP budgetary review process and will compete with other IEP projects for funding. Some portion of the proposal may be broken out for separate funding by CALFED or other sources. Some key points made in Bruce's presentation.

- The actual field work will not concentrate on trying to assess overall losses of delta smelt to predators, in part because the relative scarcity of hard bony parts makes detection of delta smelt in stomach analyses difficult. With regard to predation, the object is to explain the uncertainty regarding distribution and abundance of delta smelt and if this objective is realized, without specific focus on predation, then the relative importance of predation should become apparent.
- The biologists will try to obtain as much information as possible from all delta smelt captured in sampling program. For example, a smelt captured in the fall midwater trawl should be

preserved for later analysis of otolith microstructure as well as macroscopic and microscopic examination of the internal organs.

- The program will also result in better characterization of the metadata that are used to describe the field sampling programs. These metadata are particularly important since many of the programs have been modified over the years - for example, changes in net size and mesh size.

Discussion and Questions

1). By not focusing part of the IEP program on predation, it seems like you may be neglecting an important factor - for example, the loss of delta smelt larvae to inland silversides. Response: We are looking at the possibility of studying predation of losses of delta smelt in such specific locations as Clifton Court Forebay.

2). Does the proposal include analysis of existing data? Response: Analysis of existing data will continue as part of the white paper process and routine IEP programs but this is not part of the proposed research strategy.

3). Are you aware that IEP has funded Wim Kimmerer and Matt Nobriga to develop a conceptual model of the impacts of predation on delta smelt? Response: Yes.

4). Comment to the effect that the section 10 permit for DFG's striped bass management plan included some local predation studies. Response: These studies seem to be directed mainly to losses of juvenile Chinook salmon to striped bass - particularly near structures.

Abundance Indices: Refinements and Uses

Kevin Fleming (Fish and Game) described the uses, and some of the limitations of the indices that have been employed for years to characterize the abundance and distribution of delta smelt, with the focus on the summer townet survey, the fall midwater trawl and the 20mm survey. The first two sampling programs (townet and midwater trawl) were originally developed to describe the annual abundance and distribution patterns for striped bass but do provide information and indices for delta smelt. The 20mm survey was established specifically for delta smelt - originally to help make operational decisions. There are two additional sampling programs, the Suisun Marsh sampling program conducted by University of California, Davis (UCD) and IEP's San Francisco Bay study that also provide information on delta smelt distribution and abundance.

Historical delta smelt abundance as depicted by three of the indices - the townet, midwater trawl and San Francisco Bay study - are shown in Figure 2. Note that the period of record is different for the three indices, but the trends are somewhat similar - i.e. low abundance during the 1980s followed by partial recovery to pre-1980 levels.

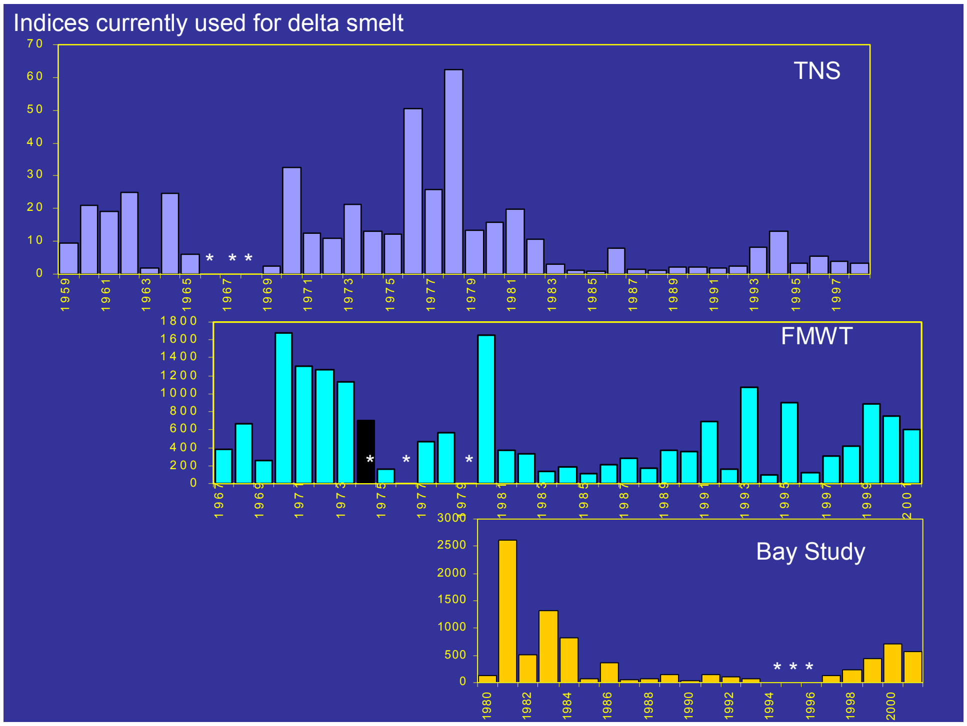


Figure 2 Historical abundance of delta smelt as indicated by three indices - the townet survey (TNS), the fall midwater trawl survey (FMWT) and the San Francisco Bay trawl survey (Bay Study). Source: Kevin Fleming, DFG.

Kevin pointed out that the indices are good for general trends and are especially good when they are all considered together - as well as catches of delta smelt in Suisun Marsh sampling programs and salvage of delta smelt at the intakes to the state and federal water projects. Biologists and managers must be careful, however, not make too much out of the indices. The indices have inherent variability due to:

The calculations themselves. In general the calculations involve expanding catch by an estimate of the volume of water the sample represents - a weighting factor developed from bathymetric charts.

Variability in the catch. As with most organisms, delta smelt distribution tends to be patchy and sample locations are fairly widely scattered. There is often large variation in catch from station to station. Also the crews do not sample in relation to tides and tidal flows probably obscure some station differences.

Survey timing. Survey timing is structured more to meet the needs of the organization than the environmental cues that might affecting smelt abundance and distribution. For example, the delta smelt summer townet index is set in the first two surveys - separated by about two weeks. Recruitment to the net may take much longer. As shown in Figure 3, there is a general relation between catches in the first and second surveys.

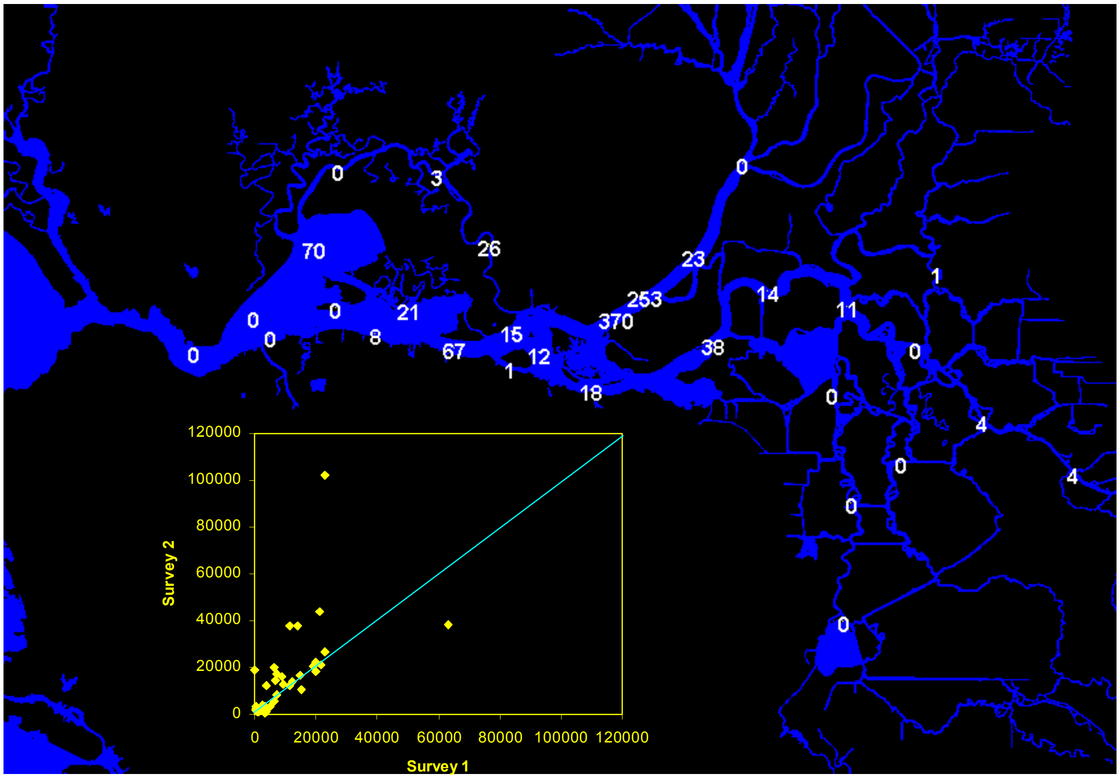


Figure 3 Comparison of smelt catches in surveys 1 and 2 - summer townet survey. Note that surveys are conducted about two weeks apart in the early summer. Source: Kevin Fleming, DFG.

The result of this inherent variation in the indices is the wide error bars around them, Figure 4.

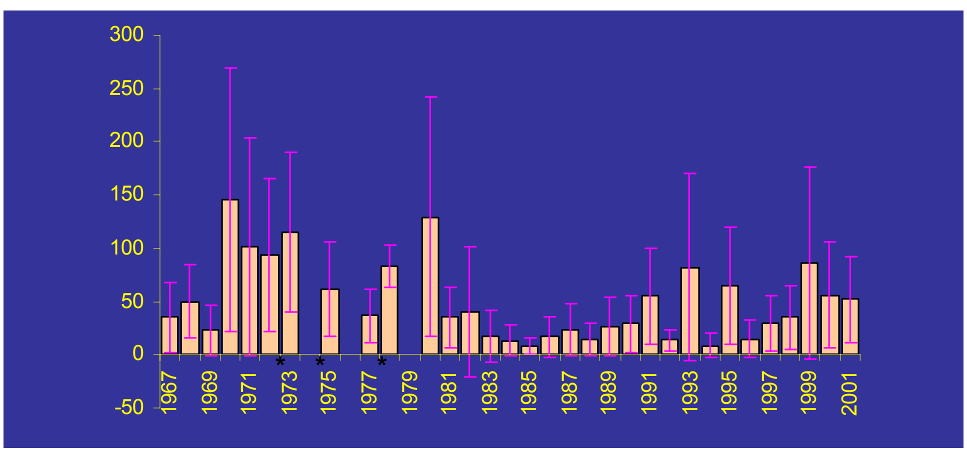


Figure 4 Error bars around the Fall midwater trawl annual indices of the abundance of prespawning delta smelt. Source: Kevin Fleming, DFG.

The townet and midwater trawl indices have an area based weighing factor. As shown in Figure 5, the weighting factor does not seem to have much impact on the use of the index - i.e. simple catches provide about the same amount of information.

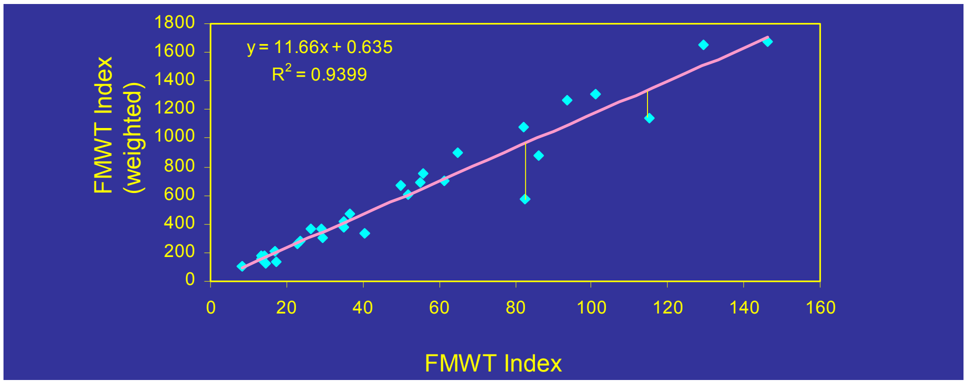


Figure 5 Comparison of weighted and unweighted fall midwater trawl indices of the abundance of prespawning delta smelt. Weighting is based on volume estimated to be represented by trawl stations. Source: Kevin Fleming, DFG.

Over the years biologists have used the summer and fall indices to determine if there is a stock-recruitment relationship for delta smelt. Kevin plotted various versions of the two surveys - Figure 6 - to visualize the relationships. (The Miller townet survey index is a proposed modification to the standard calculation designed to take some environmental information into account - Miller 2000) The geotns and geofmwt are the geometric means instead of simple averages. All plots indicate that there is some relation between summer abundance (juveniles) fall abundance (pre-adults) but there is considerable scatter.

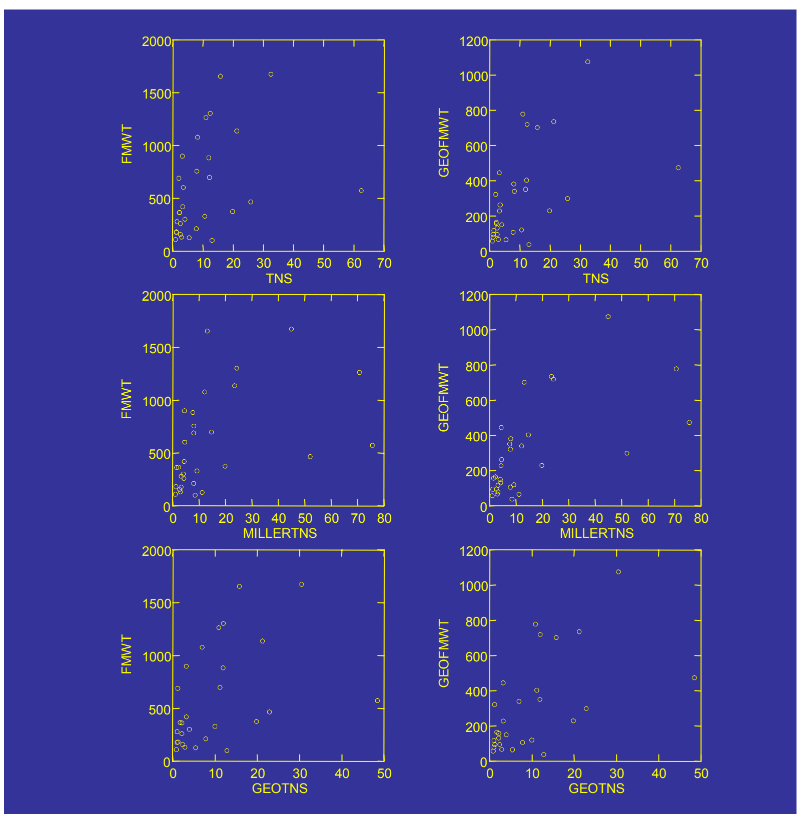


Figure 6 Comparison of summer townet and fall midwater trawl indices for each year when both indices are available. The Miller TNS is another way to calculate the summer index. Geo indicates that the geometric means were used. Source: Kevin Fleming, DFG.

Possible Use of Clifton Court Forebay to Estimate Population Parameters for Delta Smelt

Bruce Herbold and Matt Nobriga proposed that the 2,700 acre (29,000 acre-feet) Clifton Court Forebay, located at the intake to the State Water Project pumping plant, be used as a mesocosm for delta smelt studies. The forebay is gated and withdrawals (pumping) controlled. During some periods, DWR can close the gates and pump at low rates for several days. The operators can also vary pumping on a diel basis (pump at high rates at night to take advantage of off peak power costs) as long as the total daily pumping does not exceed regulatory limits. The concept is part of the IEP delta smelt research strategy; however no formal proposal or principal investigators have been made or identified. Herbold and Nobriga brought the idea to the workshop to solicit comments, questions, concerns and ideas from the audience.

The questions that could be addressed through intensive forebay related studies involve:

- **Entrainment versus salvage.** Delta smelt entering the intake channel to the SWP fish facilities can pass through the fish screens (entrainment) or move along the face of the screens to bypass pipes and from there to the holding tanks (salvage). (The smelt may also be eaten by predators in the channels or die from stresses induced in the salvage process.) If we know (can estimate) the beginning total number of smelt in the forebay when the gates are closed and at periodic intervals after closure, and estimate the total number of fish salvaged, the differences may be the numbers of smelt entrained.
- **Gear capture rates versus actual abundance.** All fish sampling gear is subject to bias and the extent of the bias is often unknown. A closed forebay, with a finite number of smelt, offers the opportunity to compare abundance data from typical net sampling with those obtained from a depletion sampling experiment (through estimates of total numbers of fish salvaged).
- **Mortality rates of isolated populations.** Again the premise is that the closing the gates isolates the smelt and periodic measures of abundance and salvage can be used to infer (or estimate) mortality rates.

The proposal specifically focuses on the April 15 - May 15 period each year when the Vernalis Adaptive Management Plan (VAMP) study typically results in low pumping - as low as 1500 total (CVP plus SWP) exports. This is also a period when delta smelt larvae and early juveniles are present in the South Delta.

The sampling design could be based on the following techniques or a combination of them.

- Catch all the smelt - would not work unless time and money were not a problem and even then it would be difficult. Catching all the smelt could include hanging a huge, small mesh net downstream of the fish screens.
- Use mark-recapture techniques. As will be shown later, it is possible to mark larger smelt but techniques for catching and marking larval and early juvenile smelt are not available.
- Depletion sampling of a closed area.
- Take water and smelt into forebay and close gates.

- Use variety of gear, including salvage, to estimate abundance.
- Sample to depletion.

Depletion sampling is the preferred alternative. As shown in Figure 7, Herbold and Nobriga hypothesize that the catch per unit effort of smelt recovered in the salvage during depletion sampling may vary considerably depending on the pumping rate. We do not know much about screen efficiency and how it varies with pumping rates. One assumption is that screen efficiency decreases with increased pumping but this assumption has not been verified.

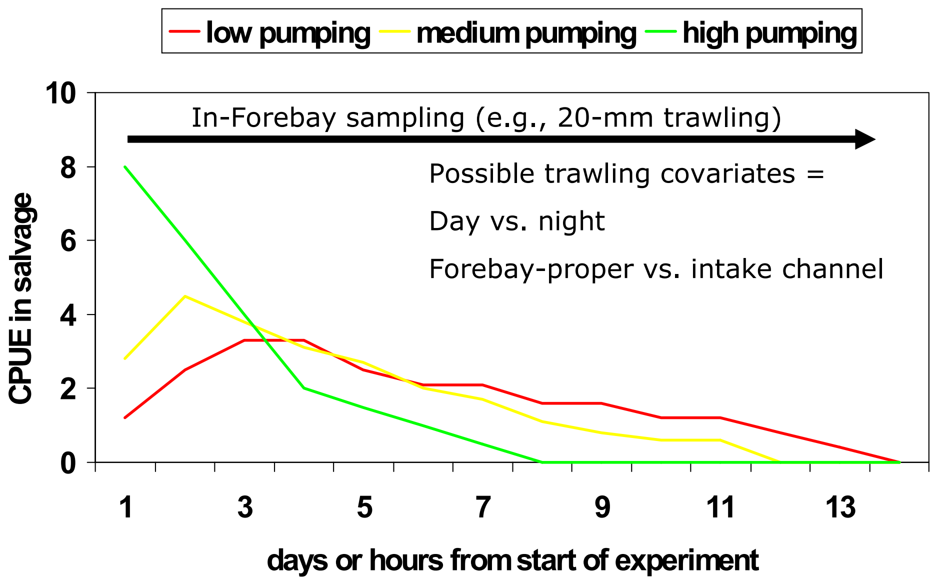


Figure 7 Hypothetical change is salvage of delta smelt at the State fish facilities after the gates to the Clifton Court Forebay are closed. Source: Matt Nobriga, DWR.

In the past year DWR conducted a couple of very qualitative pumping tests to determine if short periods of high pumping could be used to deplete delta smelt in the forebay. In one test, conducted on May 16, 2002 DWR closed the gates and pumped at night for 4-5 hours at 6800 cfs. Delta smelt salvage increased and the total salvage for the day was higher than the previous and subsequent days (by about an order of magnitude). No estimates of screen efficiency were made.

In conclusion, Nobriga postulated that the forebay studies could have long-term implications by providing better estimates of gear efficiency, develop new techniques for use in Delta channels and increased understanding of salvage dynamics - all of which could improve species protection.

Comments and Questions:

1). Wim Kimmerer commented that in depletion sampling, it would be likely that the numbers of smelt per acre foot would remain constant over time - unless screen efficiency varied.

2). Pat Coulston commented that in-forebay sampling efficiency would vary as forebay depth decreased.

3). Sam Luoma asked if new technologies, such as hydroacoustics, are being considered.

Delta Smelt Culture

Bradd Baskerville-Bridges (UCD) updated the group on delta smelt culture and how the cultured smelt are being used by researchers. The work is being conducted in facilities adjacent to the California Aqueduct on property that is part of the SWP's John E. Skinner Fish Protective Facilities. The outdoor tanks at this location were originally used to culture striped bass that had been taken from the SWP salvage. Over the past several years, funding from CALFED, DWR and IEP have been used to adapt the facilities to delta smelt culture.

This section is organized around the entire culture process from collection to availability and use of the cultured animals by researchers.

Broodstock Collection

Sub-adults are collected from the field during November and December with the assistance of DFG and USBR. Collection of wild fish begins when the water temperature decreases to approximately 10-12C. Smelt are generally 50 to 60 mm at this time of the year and survival is typically high when proper handling techniques are applied (including only water to water transfer of the sensitive fish).

Egg Collection

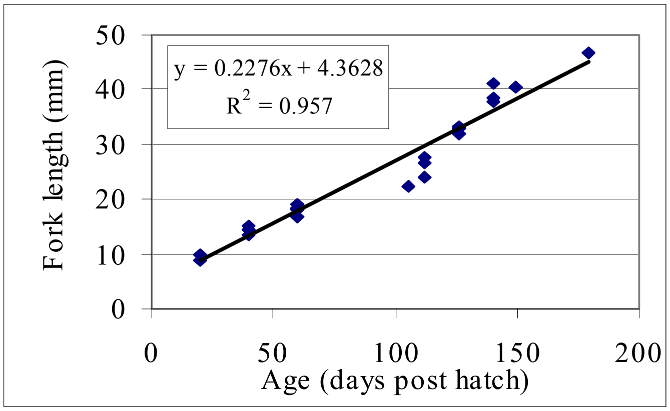
Sub-adults collected from the wild are distributed in 6 tanks (3 outside and 3 inside) and will spawn naturally in tanks during Feb.-May. After spawning commences, the demersal eggs are collected daily. About one-half of the females spawn in captivity.

Incubation

Production during the spawning period generally ranges from 500 to 2000 eggs per day. Eggs are collected and transferred to a series of 24 indoor incubators. The eggs hatch in 8 to 10 days (17C) with 50% hatch. During the incubation period extensive handling is needed to remove dead eggs to reduce the risk of fungal infections. After hatching the larvae are phototactic.

Early Feeding

Smelt larvae will not feed in clear water and require turbid conditions to elicit a feeding response. Algae are being used to create these turbid conditions with the use of recirculation systems. The larvae feed initially on rotifers and are switched to newly hatched brine shrimp on day 14 and then to enriched brine shrimp on day 21. About 5% of the larvae fail to initiate feeding and ultimately starve. At about 18mm the larvae are weaned onto artificial food. Delta smelt are sensitive and possess a prolonged larval period (2-3 months), which is labor intensive to maintain. (The larvae require daily observation to ensure that they are feeding well.) Figure 8 provides an idea of delta smelt growth. Temperature can be used increase or decrease the growth rates of larval/juvenile delta smelt, depending on the size of fish that is desired. However, the best growth rates have been obtained with 17C during the larval period (<20 mm) and 20C during the juvenile period (>20 mm).



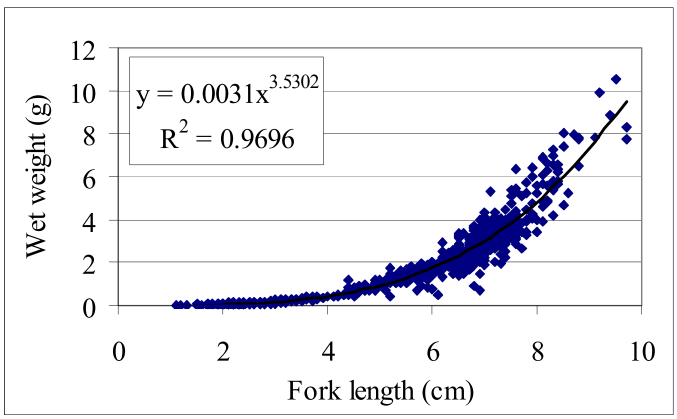


Figure 8 Growth of delta smelt in culture. Source: Bradd Baskerville-Bridges, UCD

Juveniles

At about 20 mm the fish are moved to larger tanks (150 to 200 L) and eventually to 500-L tanks. At this stage there is considerable grading and counting.

Production and Availability

Figure 9 shows production of different sizes of delta smelt for the past two years. A general observation is that production is improving every year. The following factors appear to be important to production.

- Tank size and color
- Stocking density
- Temperature
- Light intensity and turbidity

- Water quality and tank maintenance
- Food availability, including prey density
- Weaning time

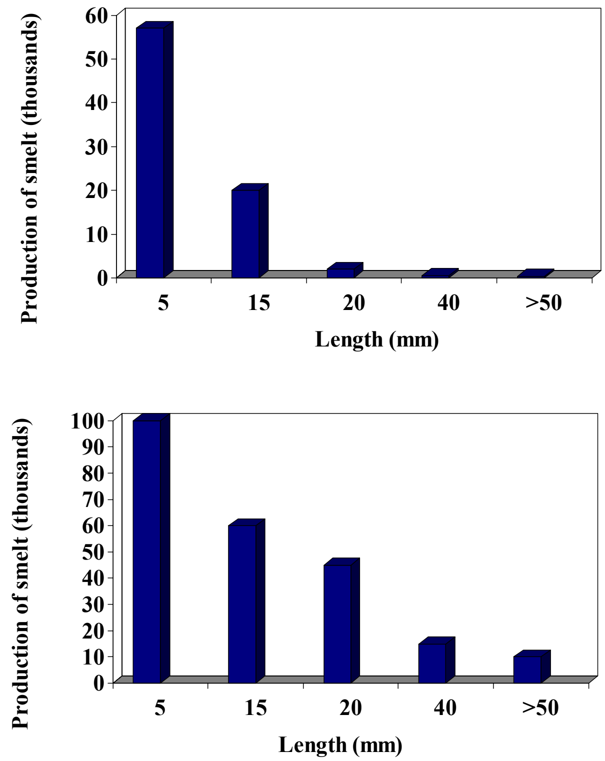


Figure 9 Production of cultured delta smelt, 2000 and 2001. Source: Bradd Baskerville-Bridges, UCD.

Figure 10 demonstrates when fish of various sizes might be available for use by researchers.

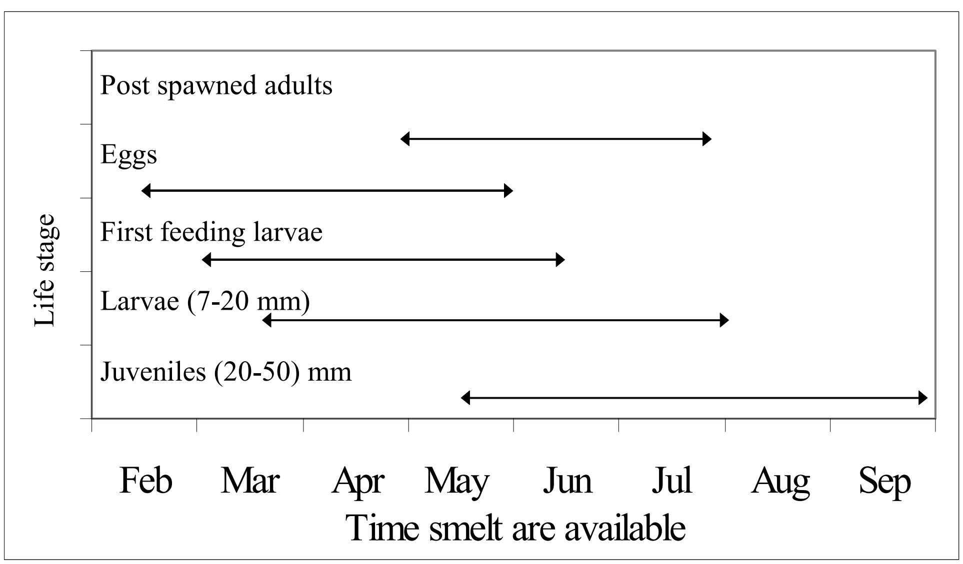


Figure 10 Temporal availability of delta smelt life stages from culture facilities. Source: Bradd-Baskerville Bridges, UCD.

Uses of Production Fish

Some of the fish produced in the aquaculture studies are being used in the following ways:

- By DFG in herbicide toxicity studies
- By the USBR in screen approach velocity and fish friendly pumping experiments.
- By the Bodega Marine Laboratory in studies to validate otolith development and prey choice (feeding behavior).
- By on-campus and on-site UCD investigators to look at how the smelt handle velocities, temperature effects on incubation, feeding behavior (prey density) and weaning time.

Conclusions

1). Progress has been made each year to supply live fish and preserved specimens to support delta smelt research.

2). Production levels are increasing and have been consistently high for the past two seasons.

3). Culturing delta smelt continues to provide useful biological information.

4). It is time to establish/define new goals for the aquaculture project.

a). Continue to expand and refine culture techniques

b). Expand the facility to increase production levels.

c). Work with researchers to more effectively address their questions and smelt needs.

Perspectives on Delta Smelt Physiology and Behavioral Research

Cincin Young, (UCD) described the results of several laboratory studies conducted over the past few years to better understand the animal's salinity and temperature tolerance and reactions (both stress and mortality) to fish screen velocity patterns. Cincin also listed the publications in which this information has been reported, or the conferences in which the material was presented in oral or poster sessions.

We have presented some snapshots of the information presented and included references to publications where readers can obtain more detail.

Critical Thermal Tolerance

Delta smelt occur naturally in a temperature range of 6 to 28C (Moyle 2002). In the laboratory 38 to 44 mm delta smelt that had been acclimated to a temperature of 17C had a maximum critical thermal tolerance of 25.4C and a minimum thermal tolerance of 7.5C (Swanson et al. 2000.)

Acute Thermal Preference (Tendency)

Delta smelt in the range of 50 to 75 mm were used to determine the temperatures the smelt seemed to "prefer" when given a choice of temperatures. The final thermal preferences depended on acclimation temperature - for fish acclimated at 19C, the final preference was 17C and for fish acclimated at 12C, it was 12C.

Temperature Effects on Metabolic Rate

Fish tested (size range of 34 to 45 mm for 19C tests and 58 to 72 mm for 12C tests) showed oxygen consumption rates of 1.03 mg O_2/hr. at 12C and 3.65 mg O_2/hr. at 19C.

Salinity Tolerance

Test fish (55 to 64 mm SL) acclimated at 17C survived for more than 12 hours at a salinity of 19 ppt. In the field most of the smelt are observed at salinities of 2 to 7 ppt, but the salinity range in which they have been found is 0 to 18.4 ppt (Barraclough 1964).

Maximum Swimming Velocity in a Uni-directional Flume

Forty-two percent of the smelt acclimated at 12, 17 and 21C failed to swim at velocities above 10 to 15 cm/s (0.33 to 0.46 ft/s). The average critical swimming velocity (27.6 cm/s or 0.9 ft/s) was independent of fish size in the range of 40 to 70 mm SL. Of the 58% of the fish that swam at the critical velocity, 62% experienced temporary failure at 10 to 15 cm/s (Swanson et al. 1998).

Swimming in Flumes with Two-vector Flows

Delta smelt exposed to fish screens typically encounter a complex velocity field with some of the water going through the screens (the approach velocity) and some water moving past the screens (the sweeping velocity). To avoid entrainment or impingement, the fish must move through the velocity field and on past the diversion. In a v-shaped positive barrier fish screen (such as found in the new secondary screens at the SWP's fish salvage facility or any large fish screen system in the south Delta) fish would move along the screen face - without being impinged - to the bypass pipe located at the apex of the V.

UCD researchers, working with the IEP, have been using a "fish treadmill" to test the swimming performance of hatchery-reared delta smelt and other fish in a complex flow field. Some preliminary conclusions from these studies are:

- Increases in the resultant velocity (between and approach and sweeping velocities) results in increased contact with the screen face and impingement on the screen.
- Increased body contact rate increases injury rate and severity of the injuries.
- Increased injury rates and severity increases mortality.
- Increases in approach and/or sweeping velocities increases mortality rate.
- Mortality is higher at night than during the day.
- Movement of fish past the screen increased with increased sweeping velocity.

Transport Stress

Blood cortisol levels and mortality were used to assess the effects of transport, confinement and handling on delta smelt. The studies indicated that:

- There was no significant stress in short-term transport.
- Confinement in small containers may be stressful.
- The process of collection, handling, transport and release is stressful to delta smelt but the fish recover in two hours.
- Stress increased with increasing resultant flows.
- Highest number of moribund fish occurred at 2 f/s sweeping velocity with 0.5 approach velocity.

Summary: What We Know

Delta smelt are:

- eurythermal
- euryhaline
- poor to moderate swimmers
- passive swimmers against high sweeping flows
- poor avoidance to screen contacts
- collection, handling, transport and release not stressful for short-term transport
- collection, handling, transport and release stressful in fish treadmill experiments
- two hours is sufficient time for recovery
- high approach and sweeping velocity combinations are stressful to delta smelt.

Summary: What Needs to be Done

1). Final thermal preference at different life stages.

2). Complete temperature effects on metabolic rates.

3). Dissolved oxygen tolerances and preferences at different temperatures.

4). Salinity preferences at juvenile and adult life stages.

5). Fish attraction and entrainment at unscreened diversions.

6). Effects of visual cues and crowding devices on fish screen contacts and passing velocities.

7). Effects of debris-related (hot spots) on fish screen contacts and fish screen passage velocities.

Spawning Cues

Joan Lindberg (UCD) summarized some of her work on delta smelt spawning cues - work that was conducted at the delta smelt culture facility. In spite of extensive field studies since the early 1990s, relatively little is known about delta smelt spawning in the wild. By learning more about reproductive cues (temperature, photoperiod, substrate, moon phase) biologists may be able to predict the location and timing of spawning and predict movement of the various life stages through the upper estuary, including the Delta. This spawning and movement information may help managers to more effectively implement and evaluate protective measures. In the culture studies, this information can result in increased production and availability of eggs, larvae and juveniles to researchers.

Although we do not know much about what triggers delta smelt spawning, it is likely to be some combination of:

- Environmental cues which elicit reproductive behavior and help synchronize spawning.
- Internal rhythms that have circadian or lunar time scales.
- Other factors such as body size, age, egg size and number of potential spawners.

Joan and her colleagues examined the effects of substrate and velocity, light level (indoor and outdoor tanks), temperature and moon phase on spawning. In this study egg production was the variable used to define spawning.

Substrate

Two tanks, six substrata (artificial tule, tank floor, empty tray, gravel, tule and driftwood) and two velocities (high and low) were used to help determine if delta smelt egg production was higher at any particular combination of variables. The water used from the Delta and the adult smelt were distributed evenly in the test tanks. The results (Figure 11) indicate that the delta smelt egg production was higher on the gravel substrate than any of the others tested and at the higher velocity.

As one participant pointed out, this conclusion may not be too helpful in the wild since there is little or no gravel substrate in the Delta. Joan indicated they have a proposal in to include large rock (new to delta, but plentiful as rip rap), and we also plan to remove the gravel and rock substrates part way through the spawning cycle, to see where smelt spawn when rock substrates aren't available.

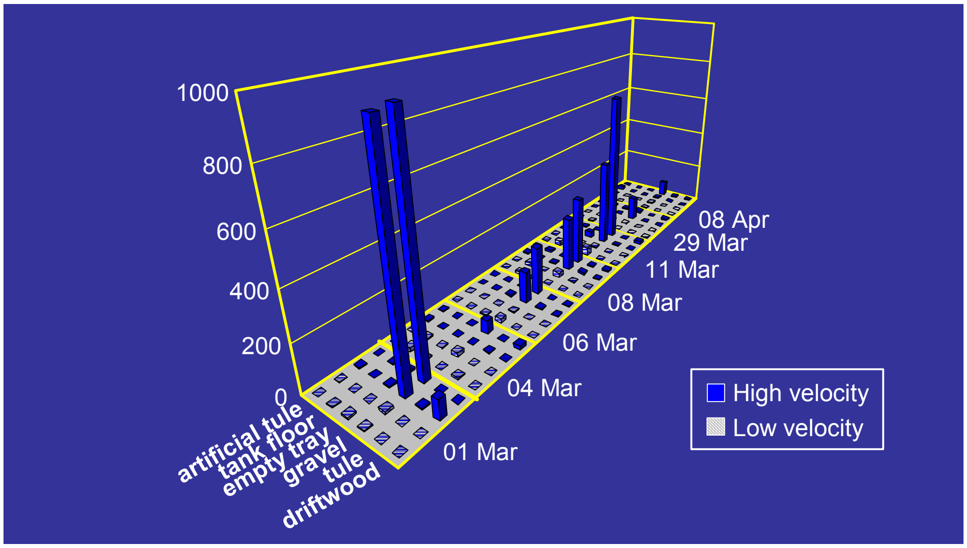


Figure 11 Delta smelt egg deposition on various substrates in controlled culture studies. Source: Joan Lindberg, UCD.

Indoor versus Outdoor Spawning

In the smelt culture breeding program the outdoor tanks consistently produced many more eggs than did the indoor ones (three indoor and three outdoor, Figure 12). Hatching rate was also higher in the outdoor tanks (Figure 13).

Figure 12 Total eggs collected over time in culture studies, indoor and outdoor tanks, in 2001 and 2002. Source: Joan Lindberg, UCD.

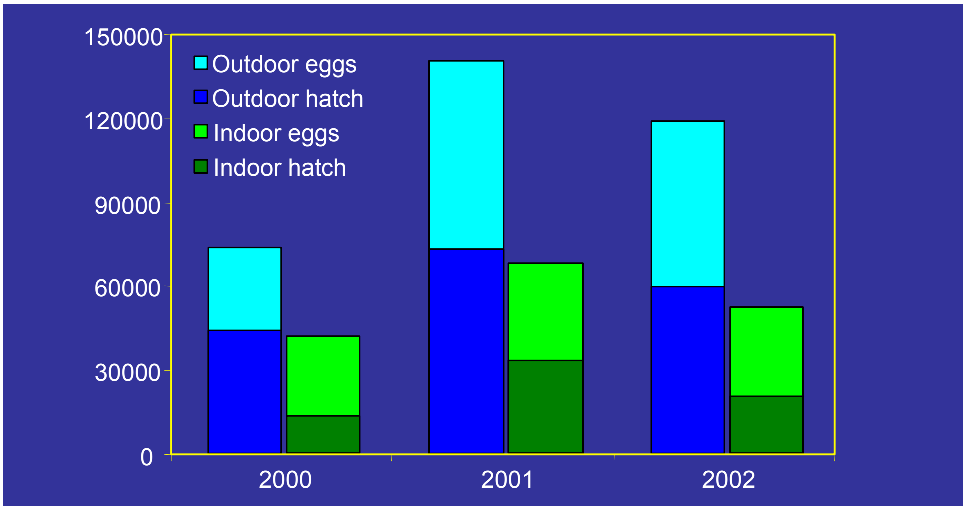


Figure 13 Total delta smelt egg production and percentage hatch in culture studies - 2000, 2001 and 2002. Source: Joan Lindberg, UCD.

Temperature

Spawning began around 10C in both the indoor and outdoor tanks and extended to about 15C (Figure 14). Joan noted this finding was in contrast with previous three years of data (1997-1999) showing spawning was initiated on spring warming trend at about 14 to 15C. So, role of temperature as spawning cue is uncertain.

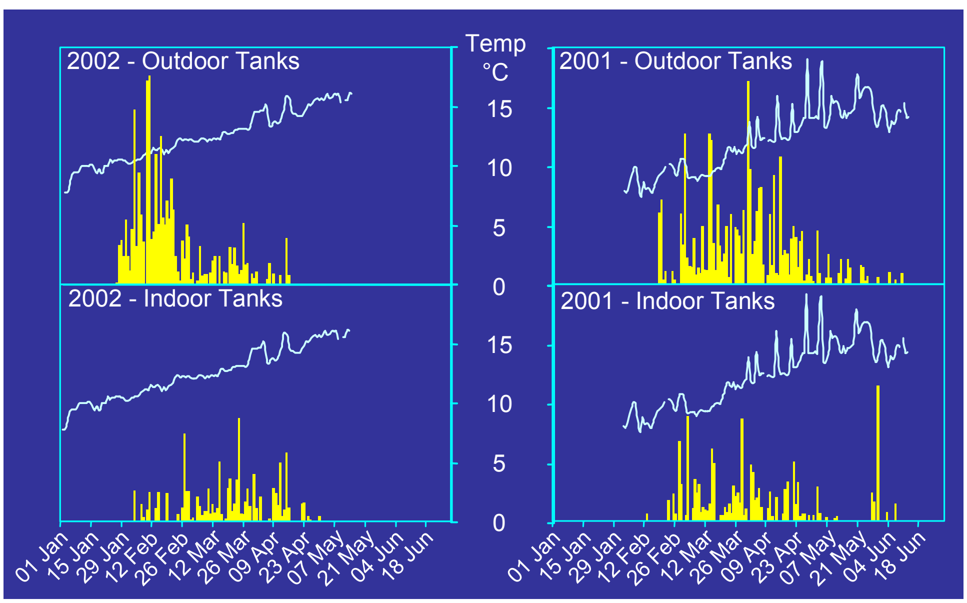


Figure 14 Delta smelt spawning (egg production) and water temperature -indoor and outdoor tanks, 2001 and 2002. Source: Joan Lindberg, UCD.

Lunar Cycle

There may be a relationship between indoor fish and lunar phase, but light intensity (or increased day length) appeared to be more important in outdoor fish. (Figure 15).

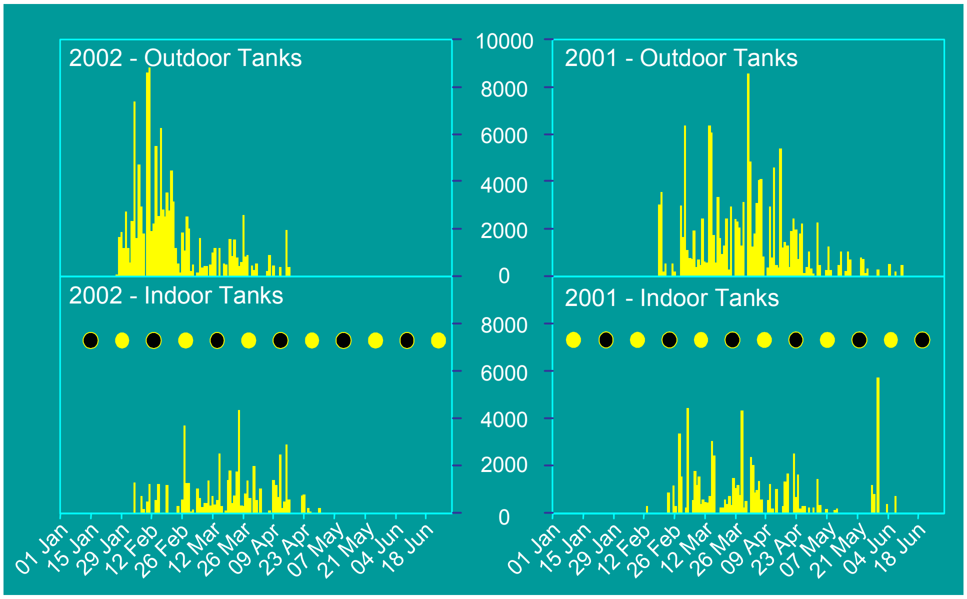


Figure 15 Delta smelt spawning (egg production) and lunar cycle - indoor and outdoor tanks, 2001 and 2002. Source: Joan Lindberg, UCD.

Joan closed the presentation by describing some proposals for additional work such as:

- Testing additional substrata and water velocities - including more replicates.
- Test egg adhesion
- Assess reproductive status of wild and captive brood fish.

Delta Smelt Research at the Tracy Fish Collection Facility

Brent Bridges (USBR) described some of the work now being conducted at the Tracy facilities - located about one mile from the SWP intake. Although the basic design of the two facilities is similar, the Tracy fish protection facilities were constructed in the 1950s (SWP in 1968) and the 1992 Central Valley Project Improvement Act (CVPIA) required the USBR to update and improve their facilities. The delta smelt research is one of components of a major study to obtain the information needed to increase fish protection at the Tracy facilities.

As background and a refresher on the workings of a fish screen and associated devices, we have included three figures from the slide presentation. Figure 16 shows the Tracy facility as it looked in 1995, Figure 17 as it looks now, and Figure 18 a schematic of the fish protection facilities. Fish encountering the louver screens can go through the 1-inch openings, or move along the screen face to enter one of the bypasses. If they enter the bypass, they are rescreened (concentrated) at the secondary louver system. The bypass from the secondary louvers leads to holding tanks. The numbers, sizes and species of fish in the holding tanks are periodically estimated and recorded. The salvaged fish are subsequently loaded into transport trucks and hauled back to the Delta away from the draft of the state and federal pumps. There may be losses to predators about any place in the system and aquatic weeds and other debris can clog the screens and holding tanks. Unlike the state operation, the Tracy intake diverts directly from the channel, thus the screens are subject to tidal and flow-induced water level fluctuations.

Brent specifically discussed four delta smelt studies being conducted at Tracy - separating delta smelt and wakasagi, tagging delta smelt, fish friendly pump tests and secondary louver efficiency tests.

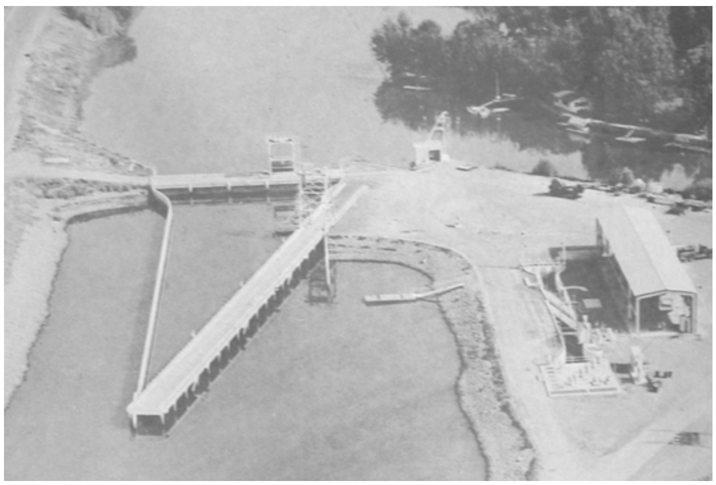


Figure 16 The Tracy Fish Collection Facility in 1955. Source: Brent Bridges, USBR.

Figure 17 The Tracy Fish Collection Facility in 2002—many of the additional buildings are used in the research efforts. Source: Brent Bridges, USBR.

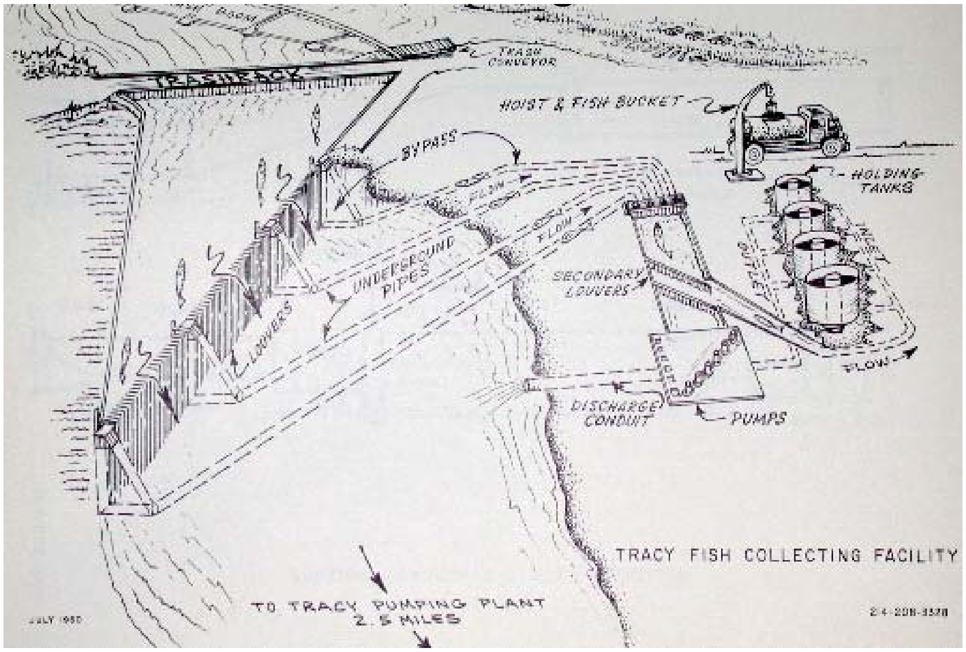


Figure 18 Schematic diagram of the fish movement through the Tracy Fish Collection Facility. Source: Brent Bridges, USBR.

Delta Smelt and Wakasagi Identification

Johnson Wang and Rene Reyes have used wild and cultured fish to develop a key that can be used to distinguish the native delta smelt from the wakasagi (pond smelt) that were introduced from Japan in the 1950s and planted in reservoirs in the Delta's watershed. Wakasagi are now found in the Delta and may be common during wet years. Since they were once classified as one species it is not surprising that it is a challenge to tell them apart.

The key uses a combination of morphometric measurements, pigmentation and air bladder inflation to distinguish the larvae and early juveniles of the two species. They plan to publish the key as an IEP technical report.

Tagging Delta Smelt

The USBR biologists have been using a photonic tag technology to inject colored plastic globules in the dorsal or caudal fin of smelt in the 50 to 110 mm range. Thus far they have tagged more than 1200 delta smelt and 2000 wakasagi with post-tagging mortality generally less than 2%. The tagged fish are used in the pumping and louver efficiency tests.

Fish Friendly Pumps

One of the modifications being considered for both the Tracy and new Delta facilities is to move from the present below ground holding tank system to above ground holding tanks and using fish friendly pumps to move the salvaged fish from holding tanks to transport trucks. Bureau biologists have recently been testing a commercial pump called the Hidrostal pump. Thus far tests indicate that delta smelt can be pumped with the Hidrostal with very low acute and latent (96-hr) mortality.

Secondary Louver Efficiency

The early evaluations of louver efficiency for the State pumps only tested striped bass, Chinook salmon and steelhead. (No field efficiency tests were conducted at the Tracy facilities.) Using tagged fish and sieve nets in the bypass, the Bureau staff conducted a series of tests to estimate the efficiency of their secondary louvers. The results of these tests are summarized in Table 1. The general results indicated that:

- larval smelt are somewhat less screenable than adults
- no significant difference between night and day screening efficiency
- in the range tested, velocity does not seem to be an important factor affecting screening efficiency
- screen efficiencies are relatively high

Table 1 Efficiency of secondary louvers at the Tracy Fish Collection Facility for screening juvenile and adult delta smelt. (Source: Brent Bridges, USBR)

Jobs	*Target velocity*	*Light*	*Juvenile efficiency*	*Adult efficiency*
1	1.09	0	0.85	0.89
2	1.09	0	0.81	1.00
3	1.09	0	0.90	1.00
4	1.09	1	0.95	0.88
5	1.09	1	0.73	1.00
6	1.09	1	0.93	1.00
7	1.60	0	0.86	1.00
8	1.60	0	0.73	0.88
9	1.60	0	0.84	1.00
10	1.60	1	0.78	1.00
11	1.60	1	0.62	1.00
12	1.60	1	0.80	1.00
13	3.10	1	0.85	0.90
14	3.10	1	0.78	0.90
15	3.10	1	0.80	1.00

Brent concluded by listing some of the Bureau's future areas of delta smelt.

- Testing oval holding tank design
- Mini flume built with rigid stream modules
- Tagging smaller fish
- Recovery system downstream of louvers
- Water to water bucket system for emptying holding tanks
- Testing bucket efficiency in 10-minute counts used to estimate number of fish in holding tanks.

Hydrodynamics Links to Delta Smelt Distribution

Cathy Ruhl (USGS) described hydrodynamic tools that can help biologists understand flows in Delta channels and, in turn, potential consequences of these flows to delta smelt movement. Examples of flow fields of possible consequence to delta smelt include:

- Effect of agricultural diversions on channel flows.
- Net flows near the intakes to the CVP and SWP and how they change in response to pumping.
- Velocity structure in Delta channels - data which could be correlated with fish abundance to see how fish react to flows.

The basic tools available for study of flows in the Delta consist of a long-term flow monitoring network (Figure 19) consisting of 17 stations collecting 15-minute data, special studies that involve short-term (three months or so) deployment of current meters and multi-dimensional modeling. These data can be used to develop current maps of such areas as near the intake to Clifton Court Forebay - the "zone of influence." These current maps also demonstrate the hydrodynamic heterogeneity of Delta aquatic habitat.

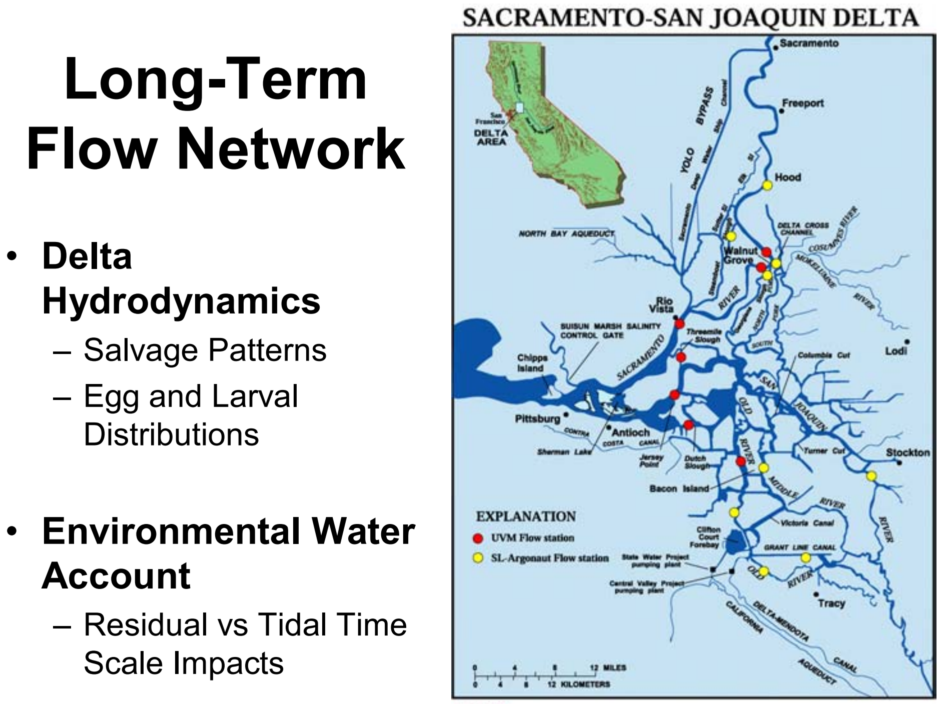


Figure 19 Long-term flow network in the Delta. Source: Cathy Ruhl, USGS.

To make use of these hydrodynamic tools requires that biological and physical scientists work closely together to design, conduct and interpret studies. The proposed delta smelt research plan supports such collaborative research.

Fish Collection, Handling, Transport, and Release Evaluation and Research Program

Bob Fujimura (Fish and Game) described an IEP proposal to examine the collection, handling, transport and release components (CHTR) of the fish salvage process at the intakes to the state and federal water projects in the South Delta. Figures 20 and 21 show how the CHTR fits into the overall salvage process - as well as some of the studies being conducted before the CHTR and concerns within the CHTR component itself.

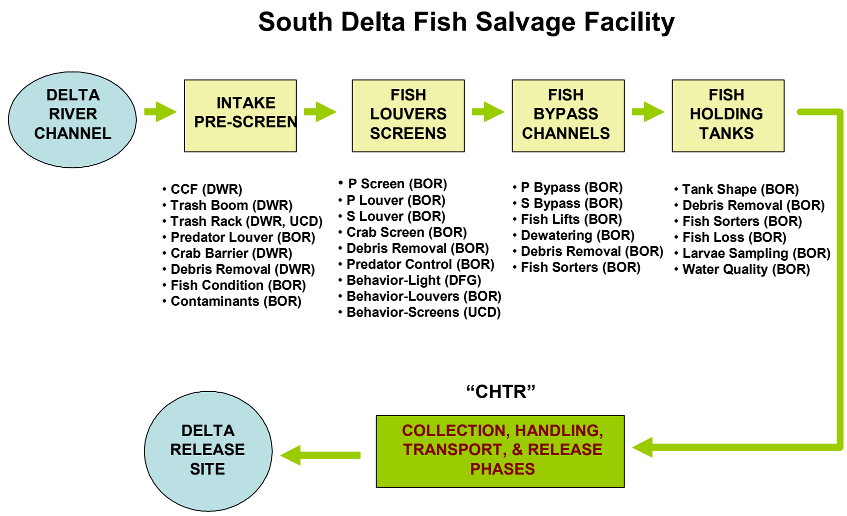


Figure 20 Flow diagram of fish movement from Delta channels to release, SWP fish protective facilities, along with lists of associated studies. Source: Bob Fujimura, DFG.

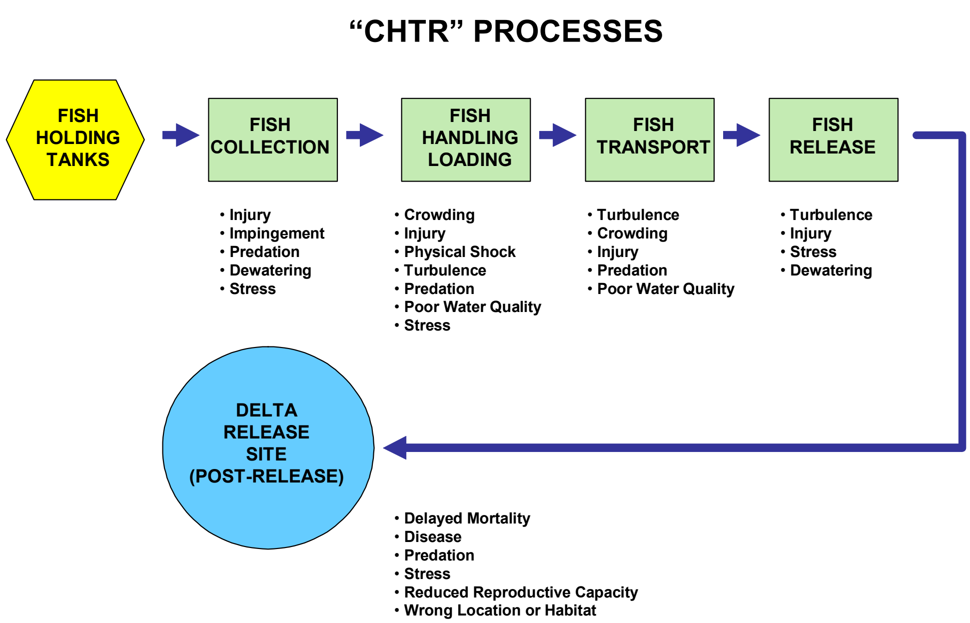


Figure 21 The Collection, Handling, Transport and Release Process (CHTR) at the state and federal fish protection facilities. Source: Bob Fujimura, DFG.

Although there have been some studies of the CHTR process in the past few years, data are limited. For example, DFG found that survival of delta smelt through the current state salvage process was low and variable, 0 to 45%. The CHTR studies are high priority with CALFED, in part because of a concern that new (and expensive) fish protection facilities may not help delta smelt recovery if the CHTR component is not significantly improved. The study will hopefully lead to new, and more fish friendly components, to improve survival of delta smelt as they move through the salvage and release process.

The general approach is to:

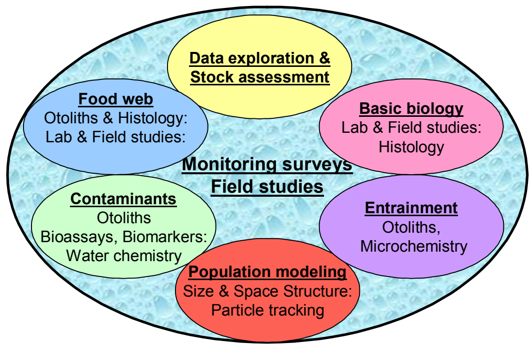
- identify key questions
- conduct literature reviews
- enhance the availability of test fish through the aquaculture program
- obtain personnel and resources
- plan and implement 5 study elements to answer:
    - a). What are the acute mortality and injury rates in existing CHTR processes?
    - b). What is the predation loss in existing CHTR processes?
    - c). Can new methods improve the survival of salvaged delta smelt?
    - d). Can diagnostic indicators be used to assess the adverse effects of the CHTR process on delta smelt?
    - e). What new CHTR concepts are feasible?

The IEP CHTR team has drafted study plans to answer the 5 key questions listed above. CALFED has agreed to fund the studies but will require that the study plans be peer reviewed, and comments addressed, before the studies begin. The peer review process could begin as early as this fall and the studies themselves begin next summer.

Field Measurement of Stressors to Understand Delta Smelt Population Dynamics

Bill Bennett (UCD's Bodega Marine Laboratory and John Muir Institute for the Environment) described an integrative and collaborative approach designed to answer questions about possible food limitation and contaminant effects on delta smelt (Figure 22). The challenge is to come up with mechanisms that quantitatively describe the effects of entrainment, contaminants and food web on the numbers of delta smelt that survive from eggs to adults (as estimated by the fall mid-water trawl). The mechanisms are probably:

- not deterministic
- interactive
- intermittent
- subtle or episodic
- difficult to identify



GOAL
Integrated approach for quantifying mechanisms regulating delta smelt population dynamics

Bennett, Jim Hobbs, UCD-BML
- Project Coordination
- Data exploration, modeling
- Otolith analyses
- Lab & Field studies

Kevin Fleming & Kelly Sousa, CDFG
- Monitoring surveys
- Field studies

Dr. Swee Teh, UCD
- Histopathology, Biomarkers
- Bioassays

Dr. Susan Anderson, UCD-BML
- Biomarkers

Dr. Kathy Kuivila, USGS
- Water chemistry

Drs. Brad Bridges & Joan Lindberg, UCD
- Basic Biology (e.g. fecundity)
- Lab experiments - specimens

Dr. Peter Green, UCD
- Otolith microchemistry

Matt Nobriga, CDWR
- Particle tracking

Dr. Wim Kimmerer, SFSU
- Population modeling
- Zooplankton studies

Dr. Bruce Herbold, EPA
- Management Coordinator
- Rabble-rouser

Figure 22 Overall study plan for integrated approach to quantifying mechanisms regulating delta smelt population dynamics. Source: Bill Bennett, UCD.

The approach is distinguish two mechanisms - food limitation and toxic exposure - and estimate the baseline performance of the population to evaluate the effects of the water projects on delta smelt. Key measurement techniques include ototlith analysis to help define and growth: histopathology to examine organ health and a “comet assay” to look at the genetic response to contaminants.

Food Limitation?

The food effect study plan (Figure 23) consists of several interrelated components to address several hypotheses. The decline of one of delta smelt’s early food sources—*Eurytemora*—and the appearance of the Asiatic clam (*Potamocorbula*) has lead to food limitation through a reduced estuarine food base.

Contaminant Effects Study Plan

This component is shown conceptually in Figure 24, along with hypotheses it is intended to address. Field studies by the USGS under the direction of Kathy Kuivila do show that pesticides occur in the same area and time that delta smelt are found and that the smelt contain elevated concentrations of such compounds as molinate, thiobencarb and metolachlor. Analysis of delta smelt livers does indicate some possible damage (data from Swee Joo Teh, UCD). In spite of high pesticide concentrations in the fish, it presently does not appear that there is much actual damage to the fish. Genetic analyses also indicate that any effect is relatively small.

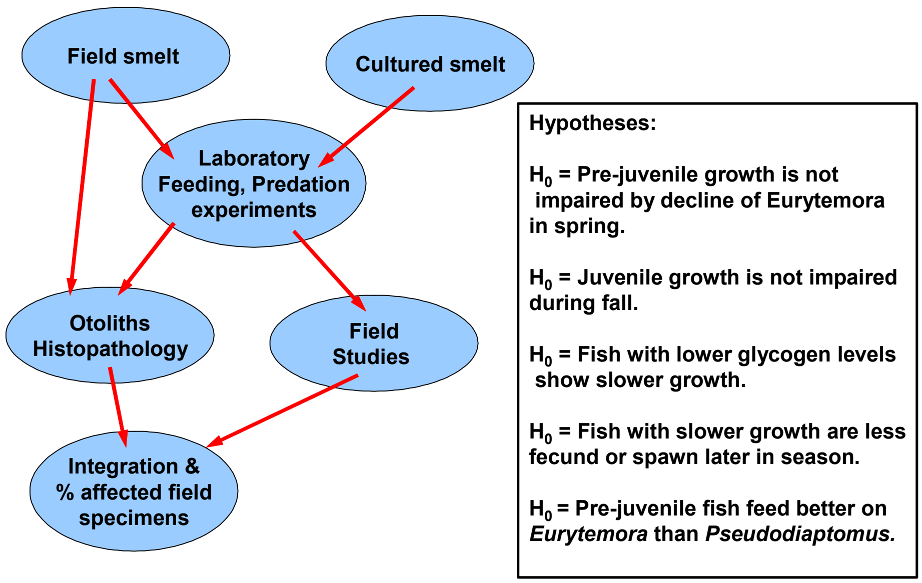


Figure 23 Food web effects study plan. Source: Bill Bennett, UCD.

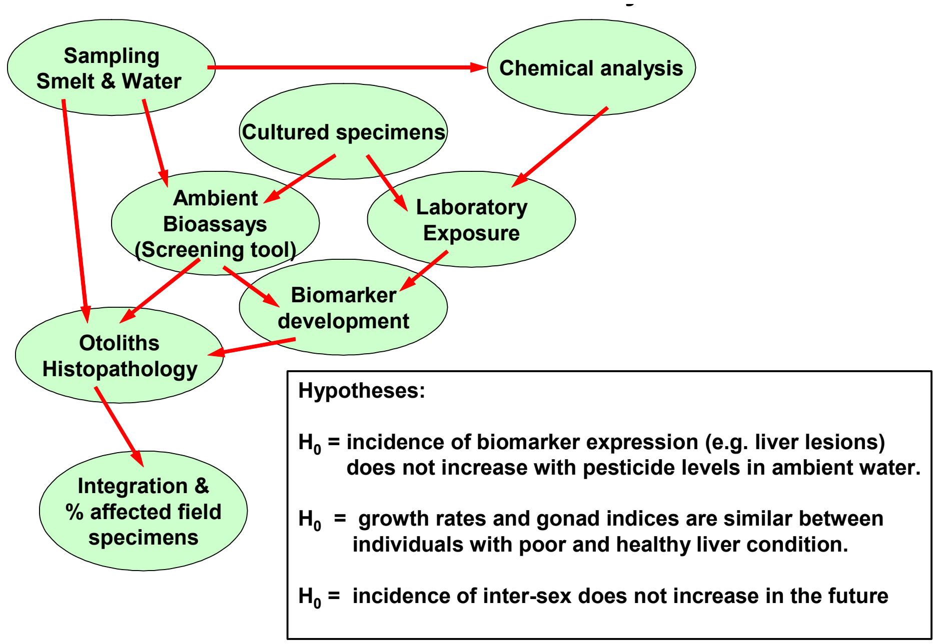


Figure 24 Contaminant effects study plan. Source: Bill Bennett, UCD.

Entrainment Effects Study

The question, hypotheses and conceptual study plan are shown in Figure 25. A subset of this plan is to use cohort analyses to look at how well the individual cohorts do in terms of their contribution to the abundance indices and to salvage. Otolith analysis and size distribution can be used to determine cohorts. For example, in Figure 26, there was only one cohort in 1997 and several cohorts in 1999. Cohort 1 in 1999 made up about 73% of the salvage but only 6% of the summer townet index. On the other hand, cohort 4 made only a minor contribution to salvage and the townet index. Was this finding due to differences in gear efficiency or did the fish in Cohort 4 die from food limitation or the effects of contaminants? Population modeling may help assess why different cohorts do or do not contribute to the overall population.

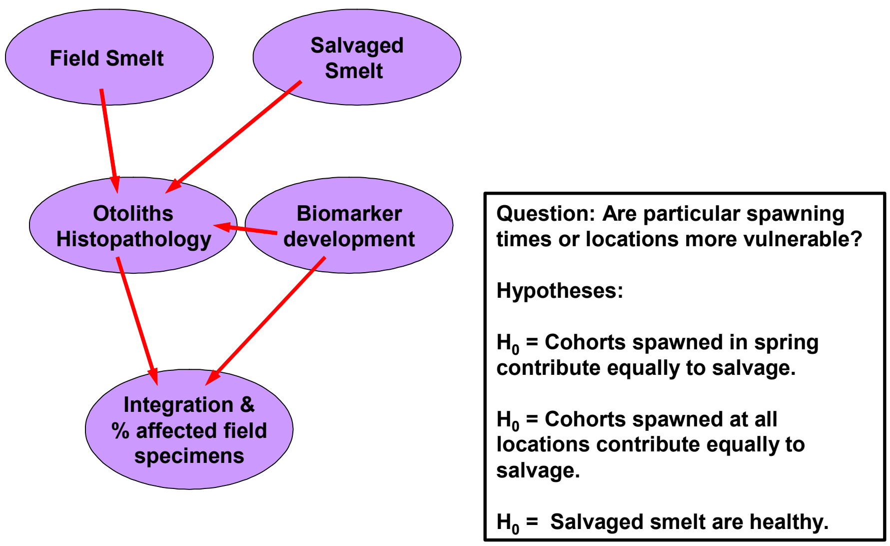


Figure 25 Entrainment effects study plan. Source: Bill Bennett, UCD.

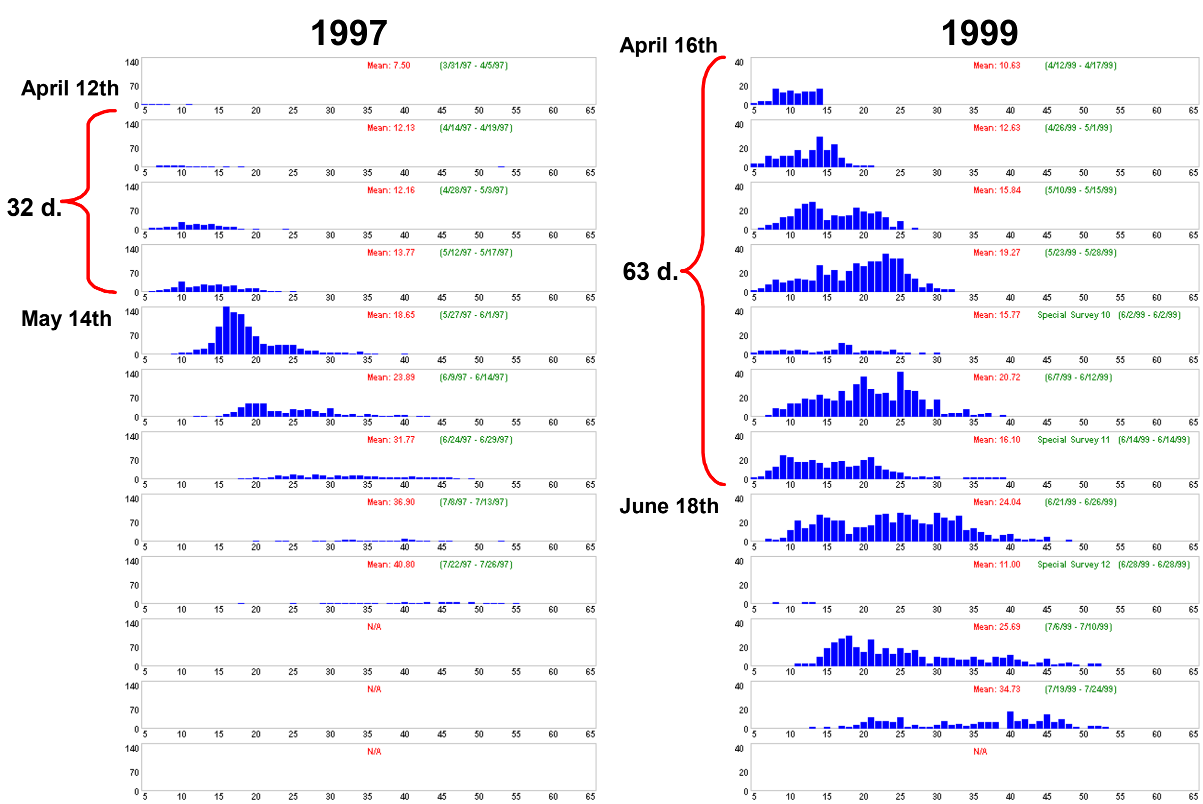


Figure 26 Delta smelt cohorts in 1997 and 1999. Source: Bill Bennett, UCD.

Bill concluded his presentation by posing the same general questions as in the research strategy but with some subquestions:

1). What controls abundance and distribution?
   a). What key factors regulate fecundity and spawning?
   b). Do 2-year old fish matter?
   c). Are there predictable patterns in the likelihood of cohort survival?
2). What factors threaten delta smelt's continued survival?
   a). Are bottlenecks to feeding success important?
   b). Are potential contaminant effects worth further concern?
   c). Are there temporal or spatial patterns to entrainment effects?
   d). How do various factors interact to define year-class success?
   e). Under what circumstances do other effects mask or inflate entrainment effects?
3). What are benefits of habitat restoration, flow manipulation, etc.
   a). Under what scenarios can EWA actions decrease entrainment effects?

Research Strategy Summary and Sequence Suggestions

Bruce Herbold summarized the research strategy by emphasizing the need to balance urgency, opportunity and reality.

Urgency

- With limited environmental water available, protection must be efficient and adequate.
- CVP and SWP improvements to their salvage facilities need additional delta smelt information.
- CALFED will be going into an active phase of habitat restoration
- The status of the species is under close examination.

Opportunity

- 2003 is forecast to be an El Nino year thus temperatures may limit spawning. Unlikely to get back to back El Ninos.
- Qualitative experiments have been performed in Clifton Court Forebay at no cost.
- Preservation of collected delta smelt for subsequent analyses costs little

- VAMP is scheduled to continue, thus offering experimental opportunities and perhaps improving delta smelt habitat conditions in the south Delta.

Realities

- There is a state hiring freeze.
- State, federal and CALFED budgets uncertain.
- The smelt culture facility is not funded on a long-term basis and the present facility is not able to meet the requests for fish.
- There is no current work underway on several aspects of the research proposal.

Timing Recommendations

2003

- Design CHTR and Clifton Court Forebay studies. Conduct structured studies of the effects of pumping on delta smelt salvage.
- Scale up artificial production.
- Preserve enough collected fish to examine temperature effects
- Seek directed funding for program elements the agencies can no handle.

2004

- Scale up CHTR work as artificial production improves
- Conduct CCF sampling coupled with salvage operations.
- Continue examination of collected fish for temperature, contaminants and starvation effects.
- Incorporate results of physiological studies in facilities planning

2005

- Expand CHTR work with new elements of new elements of the Tracy evaluations
- Expand CCF gear evaluations into channels.
- Expand sampling for stressors identified in 2003-4

Overall

- Refine abundance indices
- Improve integration among researchers
- Develop additional graduate student/university involvement
- Use habitat restoration projects in Delta as tests of delta smelt habitat use.

Discussion

There was considerable discussion at the end of the formal presentations. We do not try to capture the entire discussion but believe it important that some of the points or questions be identified in the summary report. The comments and questions are attributed to individuals. The objective is to make the questions and comments available to delta smelt researchers to help formulate their study plan. Duplicate comments and questions are retained to capture the view of the individual.

Kevin Fleming

- When are fish threatened by something we have control of?
- What leads to formation of multiple cohorts?
- How close are delta smelt to extinction?
- Can we develop a tool to tell us how many delta smelt there are?
- Are there tools that allow us to track individual animals - e.g. genetic or heat markers?
- What are spawning cues in the wild?

BJ Miller

- What controls abundance?
- What is the probability of extinction?
- How is abundance in one year related to abundance in the next?
- Why is fall midwater trawl index most closely tied to index two years earlier than to the previous index?
- Why is fall midwater trawl index better in dry year following a wet year?

BJ used the fall midwater trawl to develop an estimate of the numbers of adult delta smelt and came up with an estimate of 200,000 to 800,000 fish. He made a paper version of the paper available to attendees and indicated his computer program is available.

Tina Swanson

- Applauds the workshop and thinks this provides the most comprehensive showcase for the research strategy.
- Hopes the workteam will follow through and incorporate comments received in a revised workplan and will implement the plan.
- Tina noted that the delta smelt occupies a very restricted habitat in one of most modified estuaries in the world.
- With regard to the delta smelt's vulnerability to extinction, the state and federal endangered species acts have already made this determination.

- The ESA does provide for delisting when the species has recovered - how do we determine recovery? We need to understand the relationships between its environment and population health.
- The EWA is one of the tools to help recovery but we didn't hear much about it at this workshop.
- There was also little discussion of existing data sets. We have great data sets but not everyone is aware of their existence and accessibility. Analysis of existing data sets can provide information to managers now - they don't have to wait for long-term research projects to be completed. Managers need data now to help make decisions regarding the EWA, south Delta facilities and habitat restoration.
- She is somewhat frustrated by the lack of progress in getting to the bottom of delta smelt questions - lots of discussion but not as much action.

Kim Taylor

- Need both short-term and long-term time frames in the process leading to better understanding of the delta smelt's environmental needs.

Zach Hymanson

- Zach and Matt Nobriga evaluated the possible use of EWA assets to move and maintain delta smelt below the confluence. To achieve this movement, if it could realized, all EWA assets would be gone in a week.
- It looks like temperature was an important factor in determining the number of cohorts in the two years mentioned by Bill Bennett - 1997 and 1999.
- Smelt tend to disappear from the Delta when temperatures are in the 20-25C range - near their upper lethal limit.
- The IEP is a good place to get the data sets together and make them available - this is part of the research strategy.
- Need to better understand the interrelation of hydrodynamics and delta smelt abundance.

Roger Guinee

- The research strategy being proposed can yield information important to managers.
- This is the second year of the EWA and data and analyses are important to evaluating the benefits of the EWA.
- In the past monitoring data and other information have helped develop the delta smelt decision tree. The tree is a working document and it will be revised as more information becomes available.
- We need to avoid the 1999 type crisis (high take at the pumps) and the monitoring and the EWA process will help biologists and operators in this effort.
- We will have to evaluate population benefits of EWA and other actions to protecting and restoring delta smelt.

Jim White

- Each time we get together we turn over a few more rocks and in the process increase our understanding of delta smelt.
- Echoes many of Tina's comments.

Sam Luoma

- Thanks to everyone for participating in the workshop.
- Where are we? At the end of four years we will evaluate if EWA assets have helped protect/ restore delta smelt and other fish. Periodically assembling and addressing the state of knowledge about these fish is important to that evaluation.
- Conclusion last year was that science concerning delta smelt could be improved; each time we convene a group like this we learn more about what our existing studies mean, but we need to increase the investment in science and thereby increase the rate at which we build new knowledge.
- CALFED has funds to help move forward on the issues listed below, but contracting continues to be a challenge.
- Four areas of improvement in our state of knowledge are important:

  a). *Improved effectiveness, cohesion and collaboration within the existing effort.* Formation of the Delta Smelt Work Team under Bruce Herbold and Bill Bennett has helped move us toward that goal.

  b). *Analysis of existing data.* Use of the historic data has been instrumental in improving our understanding of the threats to Delta smelt (e.g. Bennett's talk). But the rich real time, salvage and population distribution/trend data remain under-analyzed (e.g. many analyses that, we are assured, have been done have not been published in any outlet that is even locally distributed). Brian Manly's work for the water contractors is an example of how questions can be addressed with existing information. Good questions and high quality analyses of data to answer those questions are encouraged.

  c). *Monitoring should be supplemented.* For example the studies that monitor, assess and evaluate relative effects of different stressors need to be expanded. Linkages with hydrodynamics need to be better understood, etc.

  d). Culturing is essential to continued experimentation, and should be sustained and sustainable support should be found.

- We need to expand the pool of researchers interested in and working on all aspects of delta smelt and similar species (e.g. longfin smelt; wakasagi). To this end the CALFED science program will be releasing an RFP early next year to support such studies. Funds for this work are available from last year's and next year's blueprint for ecosystem restoration.

Wim Kimmerer

- The delta smelt workshop in 2003 should be a data jamboree. Put the data on the table for all to see and discuss. To make this work:

a). The group will have to be smaller

b). The data and analyses will have to be distributed beforehand.

c). More focused on issues.

Comments from EWA Science Advisors

We have grouped our comments into three areas: the workshop itself, the next couple of years and the long term.

The Workshop Itself

We agree with a comment from Tina Swanson and Sam Luoma to the effect that these annual workshops provide a valuable opportunity for scientists studying delta smelt to share their results and conclusions with representatives of the agency and stakeholder communities working to recover the organism.

Although this workshop was not focused on results per se, several of the presentations did provide new information and perspectives and the organizers allowed adequate time for discussion. The workshop was focused more on the smelt themselves than on the effectiveness of EWA actions, which is appropriate given the state of knowledge. A few specific comments.

- We were particularly pleased to hear about the delta smelt research being conducted at the Tracy Fish Collection Facility and the new IEP studies being proposed to address the collection, handling, transport and release aspects of the fish salvage operation of the SWP and CVP's Delta fish protection facilities. As was pointed out in the presentations, we need to better understand the salvage process so that improvements can be made to better protect this sensitive fish species. However, given the importance of this topic, we are concerned about the lack of involvement by academic scientists in this work, and the lack of any apparent plan for frequent review of plans and products.
- The work by Joe Cech and his colleagues is an essential part of not only the salvage related studies, but increases our understanding of the animal's environmental requirements.
- The culture studies, including the presentation by Joan Lindberg, continue to increase our understanding of delta smelt biology as well as providing research fish.
- The discussion of the idea of using Clifton Court forebay as a mesocosm for delta smelt research is a proper use of the workshop format - i.e. propose an idea to an informed group and obtain their reactions, including possible changes in the approach. The actual subject matter clearly needs further discussion and refinement before it is ready for the proposal stage.
- Bill Bennett's presentation on an integrative collaborative approach to understanding mechanisms controlling delta smelt abundance amply illustrated the problems inherent in

population biology, and the particular difficulty of working on a rare fish in the complex estuarine environment.

- The IEP's population abundance/indices workshop scheduled for late November, 2002 sounds like a good approach to the issue of the issue of estimating the abundance of delta smelt and other fish. We urge the workshop organizers to use the workshop format - i.e. relatively small group of scientists convened to examine specific data sets and analyses. We also hope the outside experts will be invited (possibly including member of the EWA review panel), and the results be summarized in an article for the IEP newsletter or other outlet.
- We were a little disappointed in how the proposed IEP research agenda was handled at the workshop. There was little direct discussion of the research agenda and it appeared that the agenda itself was in early draft form. It wasn't clear how the results from the workshop would be used to refine the research agenda.

The Next Two Years

We now have had two years experience with using the EWA to help protect delta smelt. We have two more seasons in which to increase our understanding of how useful the allocation of EWA water has been to the smelt population. We have a couple of recommendations about what we should be doing over the next two years.

- It appears that, in the near term, the delta smelt white paper has the best chance of providing the information needed to evaluate the benefits of the EWA and other measures being used to protect and restore delta smelt. The white paper, including analysis of existing data sets and collecting and analyzing a relatively small amount of additional data, can provide information in the next several months. It can also be used to guide the research agenda. We recommend that all resources needed to complete the white paper in a timely manner be allocated to the project.
- Four general conclusions can be drawn from the delta smelt culture work.

  a). The investigators are learning how to culture this difficult species.

  b). The culture studies are contributing to our conceptual model of how delta smelt tick.

  c). Several researchers need adequate numbers of different life stages to complete their studies - animals that can not be collected from the wild.

  d). The culture studies do not have assured funding, nor adequate facilities, to produce even close to the necessary numbers of research animals.

Given the above conclusions, we recommend that the IEP agencies, CALFED and the UCD scientists work together to develop a long-term funding strategy for this essential research component and develop realistic estimates of production capabilities and the need for animals (by life stage) by researchers.

- We recommend that the 2003 workshop be organized as an intense, data rich session. By then we will have gone through three years of the EWA and will have about all the data we will ever have to evaluate the first four years of the EWA.

- The delta smelt team completes the research agenda and submits it, as appropriate to the IEP and CALFED for funding. We have commented on the draft agenda and believe that it is a step in the right direction, but that it has a way to go before it can be seen to connect logically the needs and opportunities with the short-term activities. We recommend that the next draft be circulated to outside reviewers as part of the review process - perhaps including a request to the IEP's Scientific Advisory Group for comments. The plan would then form the basis either for one or more RFP's from the IEP or the Science Program.

The Long Term

In the long-term we believe that it important to:

- Publish the results of delta smelt research in the open literature.
- Implement a delta smelt strategy that will then be revisited and revised as new information and needs become known.
- Continue to hold workshops - not necessarily on any fixed schedule but in respond to need.

References

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Appendix A: Agenda

2002 Delta Smelt Workshop
9/4/02
Putah Creek Lodge
University of California, Davis

0850 - Welcome and workshop overview . . . . Zach Hymanson

0900 - Delta smelt research strategy . . . . .Bruce Herbold

0915 - Abundance indices - refinements and uses . . . . .Kevin Fleming

0945 - Break

1015 - Clifton Court's last hurrah: mesocosm population
parameters for delta smelt? . . . . .Matt Nobriga

1045 - Delta smelt aquaculture . . . . Bradd Bridges

1115 - Perspectives on delta smelt physiology and behavioral research . . . . .Cincin Young

1145 - Lunch

1300 - Spawning cues: Micro-habitat and seasonal cues in captive delta smelt . . . . Joan Lindberg

1330 - Delta smelt research at the Tracy fish collection facility. . . . . .Brent Bridges

1400 - Fish collection, handling, transport and release
evaluation and research program. . . . . .Bob Fujimura

1430 - Tissues and tummies: field measurement of stressors
to understand delta smelt population dynamics . . . . Bill Bennett

1500 - Break

1530 - Hydrodynamic links to delta smelt distribution . . . . .Cathy Ruhl

1600 - Delta smelt research strategy: summary and priorities . . . . .Bruce Herbold

1630 - Stakeholder input

1645 - Open discussion

Appendix B: Attendees

Virginia Afentoulis .... DFG
Bill Bennett .... UCD
Marina Brand .... DFG
Rick Breitenbach .... USBR
Bradd Bridges .... UCD
Brent Bridges .... USBR
Randy Brown .... CALFED
Russ Brown .... Jones & Stokes
Dan Buford .... USFWS
John Burke .... USBR
Paul Cadrett .... USFWS
Scott Cantrell .... DFG
Joe Cech .... UCD
Erin Chappell .... DWR
Carla Chokel .... BCDC
Mike Chotkowski .... USBR
Stephanie Chun .... UCD
Bob Colella .... USBR
Pat Coulston .... DFG
Steve Culberson .... DWR
Nicole Darby .... DWR
Cindy Darling .... CALFED
Ken De Vore .... DFG
Mike Dege .... DFG
Serge Doroshov .... UCD
Jim Eychaner .... USGS
Kevin Fleming .... DFG
Bellory Fong .... CALFED
Bob Fujimura .... DFG
Dave Fullerton .... MWD
Peter Green .... UCD
Bill Harrell .... DWR
Raymond Hasey .... Yuba-Sutter Heritage
Bruce Herbold .... EPA
Lloyd Hess .... USBR
Richard Higashi .... UCD
Nick Hindman .... USFWS
Arthur Hinojosa .... DWR
Zach Hymanson .... CALFED
Lisa Jacobson .... UCD
Wim Kimmerer .... SFSU
Elizabeth Kiteck .... USBR
Virgil Koenne .... Discovery Bay
Kathy Kuivila .... USGS
Melissa Lee .... DWR
Ken Lentz .... USBR
Joan Lindberg .... UCD
Sam Luoma .... CALFED
Brian Manly .... Consultant
Barbara McDonnell .... DWR
BJ Miller .... Delta-Mendota WA
Joe Miyamoto .... EBMUD
Tom Mongan .... Consultant
Peter Moyle .... UCD
Julie Myrah .... CALTRANS
Mike Napsted .... USFWS
Thuy Nguyen .... USBR
Matt Nobriga .... DWR
Ryan Olah .... USFWS
Ron Ott .... CALFED
Carol Oz .... DFG
Victor Pacheco .... DWR
Tracy Petit .... DWR
Victoria Poage .... USFWS
Treva Porter .... DFG
Rhonda Reed .... CALFED
Rene Reyes .... USBR
Curt Robinson .... DWR

Dennis Rondort..USGS
John Rosenfield ....UCD
Cathy Roybal ....Contra Costa County
Cathy Ruhl..USGS
Vance Russell ....Kleinschmidt, USA
Edward Salinas................................Resources Agency
Amrit Sandhu..DWR
Warren Shaul.................................... Jones and Stokes
Don Shelvock ....DWR
Rick Sitts ....MWD
Larry Smith ....USGS
Jim Snow.. Kern County WD
Rick Soehren ....DWR
Ted Sommer..DWR
Zak Sulphin ....USBR
Tina Swanson................................... The Bay Institute
Kim Taylor .... CALFED
Swee Joo Teh ....UCD
Matt Vandenberg..USFWS
Kim Webb ....USFWS
Inge Werner...UCD
Jim White...DFG
Sandra White..DFG
Cincin Young ....UCD
Dave Zezulah ....DFG

Appendix C:
Delta Smelt—A Strategy for Making IEP Research Meet Management Needs

Delta smelt
A Strategy for making IEP research meet management needs

Introduction

This document contains an overview of the conceptual models pertaining to various aspects of delta smelt biology, testable hypotheses based on those conceptual models, and the highest priority research directions to test those hypotheses. This document is intended to guide IEP and others in responding to the information needs of involved governmental agencies and interested stakeholders.

Research on delta smelt must address several issues of substantial uncertainty for the management of this threatened species. A number of water management tools and environmental protective measures could be more reliably applied if we better understood the needs of this fish, particularly CVPIA's allocation of water and other resources for environmental enhancement, reconsultation by the water projects with USFWS, and CALFED's efforts toward stabilization of water deliveries, recovery of listed species, and environmental enhancement.

The principal questions surrounding management of delta smelt can be summarized as:

1. What controls their abundance and distribution?

    The status of the population, whether in jeopardy or ready for delisting, is based mostly upon the abundance and distribution of the adult population. The various sampling programs that take place in the estuary are often examined to determine the relative abundance and distribution of the population within each year. Basic biology, including physiology and population dynamics, forms the backdrop for explaining year-to-year variations in abundance and distribution. For delta smelt, substantial strides have been made in the last few years. The recently developed ability to spawn and raise delta smelt in the lab offers the possibility of further rapid progress into their biology and physiology.

2. What factors threaten their continued survival?

    The principal management actions for delta smelt have been modification of water management operations. Quantitative measurements of the benefits of these actions have been difficult and the relative impacts of other stressors on the population of delta smelt have only recently begun to be investigated. The possible impacts of contaminants and changes in the ecosystem have drawn much discussion about their implications for the protection needs and restoration goals.

3. What are the benefits of habitat restoration, flow manipulation, and fish screening improvements for this species?

    Substantial efforts are underway to physically enhance the natural resource value of substantial parts of the estuary. These efforts are undoubtedly of value to some species, but their value to delta smelt has been largely unverified. The physiology of entrainment and the usefulness of new fish-screening efforts are a continuing source of contention and considerable sums are being committed to the improvement of fish screens at the state and federal export facilities and smaller diversions around Sherman Island and Suisun

Marsh. Fundamentally, research must help determine the relative effectiveness of protecting smelt through habitat enhancement, improved screening and salvage facilities, and manipulation of water management practices.

This comprehensive strategy addresses the next three years Oct 2002- Sept 2005. Of course, results of studies each year should be evaluated for how early results might affect later steps in the strategy proposed here. To facilitate such reevaluation, explicit conceptual models are included to clarify our reasoning as much as possible. The CALFED sponsored white paper on delta smelt currently being written by Dr. William Bennett of the University of California will provide a thorough literature review of our knowledge of delta smelt. The following conceptual models omit explicit literature references in favor of descriptions of the conceptual models that reflect our current understanding. A principal goal of this effort has been to identify interconnections among diverse research and management actions. We have not attempted to limit the scope of this strategy only to work likely to be undertaken by IEP.

This strategy proceeds by three steps:
1. Describe the conceptual model pertaining to each aspect of factors relating delta smelt to the management issues. Much of this will be more fully developed in Dr. Bennett's white paper, but here it is presented as a statement of our common understanding of delta smelt and the basis for our recommendations.
2. Describe research themes arising from the conceptual models. These are summarized by a series of separate hypotheses and some of the types of lab and field research to test them. We do not propose detailed research proposals.
3. Describe interconnections among the various factors and potential areas of synergy among the research efforts.

This research strategy is largely based on draft versions of the CalFed sponsored delta smelt white paper, the delta smelt decision tree that currently guides FWS actions for delta smelt (a copy is attached), CMARP documents, several research proposals and their reviews received by CALFED during the 2002 RFP, and a series of meetings held from December 2001 to June 2002 with leading delta smelt biologists. Meeting attendees included Bill Bennett UCD, Joe Cech UCD, Pat Coulston CDFG, Mike Dege CDFG, Kevin Fleming CDFG, Bruce Herbold USEPA, Cathy Lawrence UCD, Matt Nobriga DWR, Cathy Ruhl USGS, and Cincin Young UCD.

This document was written by IEP agency staff biologists Herbold, Nobriga and Dege and is intended to offer guidance on IEP activities and priorities for delta smelt research. At present much of IEP's research into delta smelt biology is limited by the number of agency biologists assigned to the work and the need for their involvement in more of the day-to-day management concerns. We anticipate that the ongoing state hiring freeze will continue to limit DFG/DWR involvement and require greater use of contracted biologists if this work is to be performed.

Conceptual Models

Basic Biology

Spawning

Current conceptual model. Adult delta smelt move upstream into freshwater portions of the estuary to spawn. Spawning has not been observed in natural habitats but is assumed take place on vegetation, gravel, or other solid substrates. Successful hatching is probably reduced if eggs are laid under conditions where silt may accumulate and smother them. Recent work indicates that spawning is limited to temperatures below about 18 C, much higher than some earlier reports had suggested. Duration of the springtime spawning season when temperatures are suitable is a likely limit on production from in any given year. In years when temperatures remain suitable for spawning until late in the year, some of the late-spawned production may not be mature by the following spring and so contribute to a held-over population of two-year-old fish in the subsequent year. In years when temperatures rise above 18 C before all adults have spawned, some fraction of the unspawned population may also 'hold over' as two-year-old fish and spawn in the subsequent year. Years of early temperature rise in the delta are likely to be El Nino and low outflow years and the reduced period of suitable spawning temperatures is likely to result in poor recruitment . Two year old adults, therefore, may enhance reproductive success in years following El Nino events. In years of high production of young smelt, density dependent mechanisms may limit recruitment to the adult population. However, since the decline of delta smelt abundance in 1981, there seems no evidence for density dependent effects in the population.

Comment: Events like El Nino and low outflow can be related to a reduction in suitable spawning temperatures, but also minor weather events (occurring to some degree every year) like winter heat waves and drastic cold spells early in the season could initiate an early spawn and hinder or kill developing young. We might have observed something like this in 2002 with record catches of larval delta smelt from the Cache Slough complex in Feb and subsequent poor juvenile catches in Mar/Apr downstream. This could be direct, indirect, or confounded by both interacting at some level.

Habitat use

Current conceptual model. Delta smelt actual range is a small portion of their physiological potential range. Their salinity (0-19 ppt) and temperature (7.5-25.4 C) tolerances are broad but in the field nearly all of the population is found in salinities below 6 ppt. Temperatures in excess of 18 C seem to limit spawning activity and temperatures in excess of 22 C generally precede a rapid decline in abundance. Spawning apparently takes place in edge habitats of shallow freshwater areas of the delta and occasionally in freshwater portions of Napa and Suisun Marsh. After hatching and a brief amount of rearing, larvae are distributed throughout the lower delta by tidal dispersion and river flows. Under high outflows, larvae may be found further west and dispersed more widely. By July most juveniles are usually found in greatest abundance just upstream of the low salinity zone (1-6 psu?). Adults remain near the low salinity zone until they begin their upstream movements in late winter or early spring. At all life stages delta smelt are found in greatest abundance in the top 2 m of the water column and usually not in close association with the shoreline. Except for spawning, delta smelt's greater apparent abundance in shallow water habitats is at least partly a result of biases in some sampling gear that sample more of the top 2 meters when in shallow sites than in deeper habitats.

Comment: Or at the freshwater edge of the LSZ (freshwater-2psu)

Comment: This year's Spring Kodiak Trawl and subsequent 20mm larval catch leads us to believe that this movement might extend into spring.

Stressors

Current conceptual model. Four principal categories of stressors are expected to reduce the abundance of delta smelt, at least in some years: feeding success, predation, contaminants and entrainment. Each of these stressors affect young smelt differently than juvenile and adult smelt because of their different geographic and temporal distributions. Most of these stressors can have linked impacts in that variations in contaminant effects and feeding success are expected to have their greatest impact through suppressing growth, thereby increasing predation and reducing fecundity, rather than through direct mortality. Stressors may also exert indirect effects as through contaminant-induced reductions in the abundance of delta smelt food items.

Food abundance. Throughout their life cycle delta smelt feed primarily on copepods inhabiting fresh- and low salinity brackish water in the delta and upper estuary. Numerous other prey are eaten opportunistically, but are not eaten frequently enough to support the population. Given the restricted diet, it is likely that food limitation occurs at some times and places. Interannual variation in feeding success has been documented in small larvae and is thought to be dependent on sufficient abundance of Cyclops and Eurytemora, whose spring blooms have the greatest temporal overlap with larval delta smelt hatching. After the early larval period, food limitation would likely manifest itself as reduced growth, which could lead to increased cohort mortality. Variation in cohort growth rates has been reported, but not linked to food availability. Delta smelt show a delayed switch from Eurytemora to Pseudodiaptomus each spring when the Pseudodiaptomus population replaces Eurytemora. It is not known whether this delayed prey switching has a negative impact on delta smelt.

Predators.

Delta smelt have been reported from the stomach contents of striped bass, white catfish, and black crappie and may be eaten opportunistically by numerous other species. Given the spatio-temporal distribution of delta smelt, it is likely the major egg and early larval predator is inland silverside and the major predator on all postlarval life stages is striped bass. Spawning adults moving into delta shoreline habitats may encounter centrarchid predators, but low temperatures during the winter/early spring spawning migration probably limit the metabolic demands of centrarchids. Striped bass predation may have been a mechanism for long-term density-dependence. However, mortality since the decline does not appear to be density-dependent so a predation influence is not currently detectable.

The most likely egg and larval predator, inland silverside~~s~~, appeared to vary in abundance in concert with delta smelt survival during the late 80's and early 90s. However, in recent years inland silversides have ceased to vary as much from year to year. This suggests that silverside impacts on smelt are now probably more constant and less explanatory of smelt variability.

For a rare prey species like delta smelt, with few hard body parts, distributed over an open habitat, with highly mobile predators, the sampling difficulties associated with studying predation are unlikely to become manageable anytime soon.

Contaminants.

Current conceptual model: More than 400 toxic chemicals registered for agricultural uses and a large number of contaminants from municipal stormwater and sewage outfalls enter the estuary.

Agricultural sources are untreated and unmeasured but probably vary widely in concentration and composition in time and space. There have been strong shifts in recent years toward newer types of contaminants and various regulatory efforts to reduce contaminant impacts have often generated shifts from one type of compound to another. Contaminant concentrations are often sufficient to kill invertebrates and larval cyprinids in bioassay tests. Chronic effects are reported only for young striped bass. Delta smelt may suffer from contaminant effects directly in either acute or chronic forms and may also be affected by contaminant effects on populations of their prey.

Entrainment.

Current conceptual model:

Adult delta smelt are predominantly exposed to entrainment in the months from January through March when they move into freshwater areas to spawn. Adults are in these freshwater areas of the estuary when local agricultural diversions are at their annual minima so most of the impacts of entrainment are due to the state and federal export facilities. Entrainment of pre-spawning adults is likely to be the most significant form of entrainment in managing this species, since it occurs at the time when the population is smallest and at the last stage in their life cycle.

From March through June young fish are entrained as they hatch and disperse, As they increasingly concentrate in the more saline waters of the western delta, the risk of entrainment declines. Depending on their temporal and geographic distribution, larvae may be affected by entrainment arising from local agricultural and municipal diversions, as well as the state and federal facilities. During early life stages, many young fish entrained at one location would likely have been lost to other sources of mortality; this normal high mortality rate on young life stages greatly complicates any evaluation of the impact of individual mortality sources. High SWP and CVP export rates may alter delta hydrodynamics sufficiently to slow the westward dispersion of young fish and expose them to higher overall mortality sources in the delta for longer periods than they would otherwise suffer.

At present, entrainment impacts are based on estimates of the numbers of smelt collected by the salvage facilities. Pre-screen mortality, louver efficiency, and post-release mortality are largely unknown, so it is not possible to estimate entrainment loss. However, entrainment loss is generally thought to increase with increases in salvage. Related to these questions are the impacts of varying pumping rates, varying operations of the Clifton Court Radial Gates, and the zones of influence within which smelt are subject to entrainment by the state and federal facilities.

Delta smelt are sensitive fish requiring proper environmental conditions for successful handling and transport. Handling mortality is assumed to be 100% in the USFWS Biological Opinion and laboratory results of stress response ~~supports~~ this assumption. DFG recently completed field tests of handling effects on delta smelt and found mortality rates in all experimental and control groups ranging from 94-100%. Smelt in culture facilities are regularly transported with very limited mortality but the ability to transport fish salvaged from the export facilities is unclear. Post-release mortality for successfully salvaged fish also may be high due to large groups of predators that are attracted to the fixed release sites. However, post-release mortality has not yet been estimated for any species and delta smelt are a poor candidate for such studies due to their high levels of mortality during salvage and trucking.

Research themes

Eventually, the protection and management of delta smelt will benefit from a mathematical model that incorporates the dominant factors driving their abundance. At present, our knowledge of delta smelt absolute abundances and of the inter-annual variation in factors that govern their abundance and distribution are inadequate to support a quantitative model. This strategy aims toward a quantitative life cycle model for delta smelt by separately estimating the impacts of several environmental stressors on smelt population size and/or the fecundity of spawning adults. Three main themes need to be pursued: basic biology, stressor impacts, and population quantification.

We are well-situated to address a number of the pressing delta smelt issues in the next three years. El Nino conditions are expected to begin developing in late 2002. This should lead to a warmer than usual spring in 2003. Thus, we will be able to examine the expected effects of temperature: truncated spawning season, reduced production of young-of-year and a portion of the adult population holding out to spawn in 2004. Hydrologically, El Nino years tend to be either extremely wet or extremely dry and are associated with low abundance of delta smelt in the fall midwater trawl. Therefore, delta smelt abundance is likely to be strongly limited in 2003. El Nino conditions seldom come in adjacent years so stressors on the population are likely to be very different in 2004 than in 2003. Given two different years and appropriate investigations performed in each year on the biological response of the smelt population, we should be able to examine in greater detail in 2005 the environmental factors that were tied to the population response in 2003 and 2004. If the hydrology is substantially different in 2003 and 2004, then export rates and salvage rates are likely to be substantially different, providing strongly contrasted conditions for studies of smelt densities in Clifton Court Forebay and the salvage operations.

Basic biology. Our understanding of the basic biology of delta smelt has increased greatly in recent years through laboratory studies and close examination of historical datasets. The recent improvement in our ability to raise delta smelt in the lab is likely to provide substantial further depth to our understanding of their physiology and environmental response.

The culture of all life stages of delta smelt creates a valuable resource for the research and management community:

- eggs, larvae, juveniles and adults fish can all be made available, in quantity, – many important basic and applied studies can not move forward with out this supply of delta smelt
- culture provides a supply of eggs and larvae uniquely suitable for toxicity studies. These studies require animals with known rearing history – we may not be able to meet the demand by this group as it is growing quickly.
- culture of smelt provides valuable laboratory standards in the form of preserved developmental series with known temperature, feed, and rearing conditions

Laboratory cultured delta smelt have been used for:

1. Development of a diagnostic key for distinguishing between delta smelt and wakasagi smelt larvae. (DWR), (DWR), (CDFG), (National Environmental Scientists), (USBR)
2. Evaluation of predatory effects of inland silversides on delta smelt larvae. (UCD), (BML)
3. Role of contaminants in the decline of delta smelt in the Sacramento-San Joaquin Estuary. (UCD), (BML)
4. Feeding selectivity of delta smelt on native and exotic copepods (UCD, BML), (SFSU)
5. Toxicity testing of herbicides on the survival of delta smelt larvae and juveniles. (CDFG).
6. Fish treadmill study. (UCD)
7. Experimental testing of fish friendly pumps, fish screen design, and louver efficiency. (USBR)

Future research into many aspects of the basic biology of delta smelt will rely on a supply of required number and life stage of delta smelt required by their study. The year to year variation in funding, and occasional risk of no funding limits and varies the supply of test fish.

IEP should support, either by itself or through cooperation with other funding sources, some level of stable funding for the culture of delta smelt over an extended period of time. In rough terms funding of about 250K/year will ensure the availability of up to about 10,000 – 20,000 larvae and juveniles.

Use of Historical datasets

IEP and CALFED are actively pursuing the involvement of a variety of graduate students in analyzing the very large datasets collected over the last 30 years. CALFED and the San Luis Delta Mendota Canal Waterusers Authority are funding intensive studies into the ability to use historical data to estimate population sizes. To facilitate fruitful and meaningful use of these datasets, IEP should review historical delta smelt datasets and develop an assessment of their suitability for various uses: risk of extinction, trends through time, delisting criteria, stock-recruitment, geographical distribution and its environmental cues, age-structure, etc. We should assess the range over which the various indices are reliable indicators of population abundance and the factors that limit their usefulness. IEP houses the people most familiar with the history and development of the data and indices and is the most appropriate group to ensure that data are used appropriately. This work should be done immediately to avoid wasted effort by external population estimation experts. The help of outside experts to stimulate new approaches should be pursued via IEP's and CALFED's new mentoring programs. Further field work, especially further gear comparisons, may arise from these studies to refine the effectiveness of various sampling gear.

Basic biology and environmental parameters.

We should pursue laboratory studies that focus on environmental factors that are likely to affect the wild population at each of its life stages. Temperature appears to be the primary determinant for cessation of spawning in adults, and the seasonal decline of larvae in the south delta, Napa River, and possibly other peripheral areas. Salinity seems to be a primary determinant of the spatial distribution of juveniles and pre-spawning adults. A better physiological understanding of these observed patterns is likely to enhance our understanding of the importance of other stressors, such as water management, contaminants, and entrainment. Critical limits and acute effects have received excellent attention in recent years. Sub-lethal impacts of temperature and salinity on smelt metabolism, feeding success and growth rates are important new directions. After determining the sub-lethal influence of temperature and salinity, their effect in combination with important anthropogenic stressors should be pursued.

Comment: While documented adult physiological information is available, we know very little about the larval/juvenile physiological limits. This is more feasible today with the ds culture production as our available stock.

Temperature effect null hypothesis
H_0 = Temperature does not influence the spawning behavior of delta smelt.

Experiments investigating the effects of temperature on spawning behavior could provide valuable information regarding the ability of delta smelt to retain their eggs until the next spawning season. Rejection of the null hypothesis would provide information related to the potential contribution of two-year-olds in the population.

Many proposals to CALFED have purported to provide improved spawning habitat for delta smelt via the construction of various sorts of wetlands. There is no evidence of spawning habitat limitation for this species, but we have a very poor idea of what constitutes spawning habitat. Laboratory studies of substrate selectivity is proceeding and should be supported to determine: (1) whether delta smelt eggs adhere to all substrates tested with similar affinity, (2) whether captive (wild-caught) delta smelt spawn heterogeneously with respect to substrate type (gravel, large rock, tule plant with roots, sand and driftwood, or control – empty tray), and (3) whether the distribution of eggs and spawning frequency on different substrates are associated with different water velocities.

Ho= Captive delta smelt (wild caught) will distribute their eggs evenly and will spawn with equal frequency on all bottom substrates under diverse flow regimes.

Rejection of the null hypothesis suggests that the smelt are making a choice for one or more of the bottom substrates or for a water velocity zone. If smelt are selective of substrate types, mapping of such substrates in the field may indicate whether such substrates might be limiting and what wetland restoration techniques are likely to benefit delta smelt.

For wild and cultured delta smelt, test for correlations with seasonal variables that may serve to synchronize or initiate the cycle.

Conducting a fairly frequent sampling program of fish on a localized spawning ground (females ovulating eggs and males ripe with milt) will allow measurement of several maturational parameters to test for correlations with seasonal variables (day length, water temperature, lunar cycle, water turbidity). Testing of one or more or these key variables for an effect on final oocyte maturation in laboratory reared fish, while keeping other variables constant, would also be of interest. Being able to predict the timing of delta smelt spawns should also facilitate predicting when larvae will hatch and appear downstream in Suisun Bay, or at the water export facilities in the south delta.

Ho: Delta smelt do not respond to seasonal cues (eg. changing day length or water temperature, lunar phase) with respect to maturation of gonads or final maturation of oocytes (capable of meiosis and ovulation).

Developing a reproductive profile for delta smelt which chronicles oocyte maturation (and gonad enlargement) should proceed. The current use of a gonadal somatic index (GSI; ratio of gonad to body weight) is simple and indicates that the gonads have increased in size and weight, but is quite variable (14-20%) based on body size and fecundity, and stays high for weeks (lacks precision). Determining when most of the fish exhibit oocytes at the final maturation stage (peripheral position of the germinal vesicle) is a more discreet indicator of spawning - indicating these fish should spawn within days or hours. Samples can be obtained from the Fall Midwater Trawl Survey (CDFG), ideally sampling would increase to once a week in a couple of areas where ripe fish are found. Samples should also be examined for abnormalities which could suggest relative health of eggs. Studying this over the predicted-2003 El Nino year and (subsequent non- El Nino year) would be provide a wide range of field conditions and increase the likelihood of establishing a correlation.

Stressor impacts. The importance of stressors on the adult delta smelt population probably varies substantially from year to year. Because of the results of pilot studies done to date, we suggest research emphasis be placed on possible connections between food supply and growth, contaminant effects, and entrainment effects. The goal of this research is to assess the relative contributions to the eventual spawning success of the adult population in each year. Examining the percentage of individuals showing responses to each of the possible chronic stressors will allow an estimation of how prevalent each factor is in the population in a given year and how much these effects vary from year to year. Further details follow.

Reliable estimation of the proportion of smelt showing signs of chronic impacts will require a large number of smelts to be analyzed. Fortunately, a large number of smelt are currently collected each year in the various sampling programs in the delta. Unfortunately, most smelt are not retained or preserved in a fashion that would allow estimation of chronic impacts. Each smelt collected in the field is extremely unlikely to survive and is a repository of the effects on that individual of all environmental conditions and chronic stressors that acted on that individual. Adequate samples of larvae, juveniles, and spawning adults should be collected, preserved and analyzed for the impacts of suspected stressors. Since the IEP take limit presently limits some sampling programs of the IEP, it is imperative that these samples for the evaluation of stressor impacts be collected without increasing our present FWS take provisions. Existing sampling programs can usually be relied upon to collect adequate numbers of three life stages:

> The 20 mm survey collects larval smelt and covers a wide geographic area over several months so it can potentially be used to examine spatial and temporal variability. The

survey is constrained in how many smelt they can process on deck and still get their primary task accomplished. Salvage operations collect very large numbers and are not limited by the constraints suffered by boat crews, so they could be used if the 20 mm survey fails to catch adequate numbers, although information on spatial variability is lost.

Comment: All smelt spp. (delta, wakasagi, longfin) are preserved and brought back to the Stockton lab for positive identification. Samples are then archived for 5 years.

The summer townet survey and the fall midwater trawl cover a large spatial and temporal scale but do not usually catch a large number of juvenile fish. Pooling the catch across months and across gear types may be necessary in order to adequately characterize the response of the population to various stressors.

Salmon sampling, especially during the Vernalis Adaptive Management Program, captures a significant number of pre-spawning adults. Both the Kodiak trawls at Jersey Point and the Chipps Island trawls are often limited in their operations by the by-catch of smelt. The Kodiak sampling alone captured 973 adult delta smelt in April and May of 2002. In addition, the IEP is funding a delta-wide spring Kodiak trawl for delta smelt beginning in 2003. Together these sampling programs should be more than adequate to meet the needs of delta smelt research.

Comparison of length, weight, otolith determinations of age and growth, gonad weight and condition in adults, contaminant effect biomarkers (including tumors), liver cytology and glycogen levels, and parasitism loads are all parameters that should be measured on each of the individuals collected. Desirable supporting information would be contemporaneous measures of temperature, water quality and contaminant loads, and copepod densities. Preliminary work performed in recent years should be able to estimate the minimum number of individuals needed to estimate the rate in the population, if it is necessary to limit the number preserved. However, the larger the sample size, the more likely we will be able to determine effects.

High priorities for investigation of stressor impact

Contaminant results. Incidence of liver cancer and other non-reversible biomarkers would be generally expected to increase as fish get older (and are exposed to more contaminants). In contrast, if incidences of cancers decline through time this would strongly suggest that diseased fish are failing to survive. If age-growth relationships or gonado-somatic indices are different between cancerous and healthy individuals, then the incremental impacts of contaminants on survival and reproduction must be included in the population model. Other types of biomarkers could also be used to address contaminant effects, but cancerous livers are one of the more easily measured, long-term, and biologically important candidates.

Direct mortality null hypothesis:
H_0 = incidence of liver cancers is greatest in the pre-spawning adults

Fecundity effect null hypothesis:
H_0 = growth rates and/or gonado-somatic indices are equal in pre-spawning adults with and without liver cancers

Liver histology and glycogen (food limitation) results. Starvation is likely to be almost synonymous with mortality during larval feeding stages. Juveniles and adults are generally able to survive longer without food by relying on glycogen deposits in the liver. Comparison of individual age-growth patterns and liver tissue structure and glycogen levels should show whether the slower-growing fish have impaired liver cell structure and reduced glycogen levels. By contrast, low glycogen levels may be dispersed throughout all sizes and growth rates within the population if successful feeding is primarily a result of chance encounters with suitable food patches.

Variance in feeding success should be directly reflected in the variance around the age-growth relationships for the population. Variance surrounding the age-growth relationship would be expected to decrease with the age of the population, as slower growing fish are culled from the population. On the other hand, if the variance in length increases with age, it would imply that slower growth rates are not limiting population size.

Mortality null hypothesis:
H_0 = Variance in growth rate increases from the midwater trawl to the pre-spawning adults

Fecundity effect null hypothesis:
H_0 = Fish with lower liver-glycogen levels show slower growth.

High priorities for Entrainment investigations. Data on entrainment at sites other than the state and federal export facilities are few. Data on salvage are the reverse of most other stressors in that we have good estimates of the number of fish salvaged but no basis to say what percentage of the population the numbers represent. Improving salvage data by estimating pre-and post-screen losses and the impacts of entrainment on local smelt densities is discussed below. Entrainment is unlikely to have chronic impacts on fecundity or delayed mortality and its quantitative population-level impacts can only be assessed with concurrent estimates of the total population.

One test for population-level impact can be pursued, but the power of the test is probably very low. Birth dates of the pre-adult population can be calculated by otolith examination. By comparing the distribution of the dates of when the surviving adults were 20-30 mm long with the distribution of dates in salvage we can determine if the surviving adult population came from individuals that hatched when entrainment rates were low. Similarly, the pattern of timing of exports could be compared with the timing of hatching for fish that survive to adulthood in order to test for impacts of export rates on fish smaller than 20 mm. However, if the distributions do not differ, then entrainment is simply sampling the available larval population. An egg and larval survey to determine the actual timing and distribution of smelt spawning would greatly increase the power of these analyses.

Comment: Because this can be confounded by a good hatch co-occurring in an area not influenced by the pumping facilities (Sacramento River) this might be a tough one to discern. If we were able to detect an area of hatch with a reasonable resolution? (Bill was talking about this at our last meeting). We could also determine if the adult population was derived mainly from e.g. Sac, Mokelumne, Suisun, or San Joaquin spawned fish. These data then can be related to larval, juvenile, and adult catch (20mm, TNS, and MWT) as the season progressed and an estimate of mortality at each stage and location might be possible. It's a long shot, but I thought I would toss this in.

Direct mortality null hypothesis:
H_0 = The distribution of hatching dates of the fall MWT population is not significantly different than the hatching dates of larvae.

Predation. Like entrainment, predation is assumed to have no partial or indirect effects on growth or reproductive success on an individual. Predation is also assumed to be the most likely direct cause of mortality for stressed fish, so that studies of predation rates would serve to mask the effects of other stressors. Predation in the natural habitat is also the most difficult stressor to study because the prey are not abundant, the predators roam widely, and digestion rates are probably rapid. Therefore, we do not propose direct predation studies except through its impacts on population parameters associated with each of the other stressors. The IEP has already funded a proposal (Kimmerer and Nobriga) to develop a model of striped bass predation on delta smelt. However, most of the needed inputs are unknown, so results will focus research questions more than quantify smelt losses to striped bass.

3. Impacts of predation and entrainment are always acute and so will be difficult to compare with chronic impacts until credible population surveys can be performed and a quantitative life cycle model constructed. The goal of research on predation and entrainment must focus on better quantification of population size, losses, and the environmental factors that affect loss rates. Focusing these research efforts in the relatively small and controllable area of Clifton Court Forebay is probably the best way to develop the tools that might allow expansion of techniques more widely.

Delta smelt entrainment in the delta takes place almost exclusively on mature adults (generally December-April) and on recently spawned young fish (generally March-June). Entrainment impacts are presently represented solely by numbers of fish salvaged at major diversions. Impacts of smaller diversions, the relationship of salvage to actual loss at the export facilities, and interactions of water export activities with other stressors are largely unknown.

Attempts to measure smelt entrainment at agricultural diversions have been difficult to pursue due to restricted access and lack of landowner cooperation. Where such studies have been done, very few smelt were collected, even though large numbers of young smelt were sometimes found in the adjacent waterway. A better understanding of the entrainment dynamics at the state and federal export facilities is more likely to generate useful information than continued studies at agricultural diversions. Techniques developed at the larger diversions might later studies of entrainment at smaller diversions more productive.

Adult smelt entrainment

Laboratory studies of screening physiology have focused on juvenile and adult smelt. These studies have shown various physiological components of fish sensitivity to screens including diel, temperature, and velocity responses. These data can be used to design alternative screen designs and pumping regimes. Larval fish entrainment is likely a simple function of their densities near the pumps and reducing the impacts of entrainment is probably only possible through actions that reduce their densities near the pumps.

Further laboratory investigations into fish-screening parameters should be closely tied to the development of new facilities at the State and federal export sites. Screens designed to meet the apparent stringent physiological requirements of delta smelt are more likely to suffer from increased debris loads. Physiological studies of non-uniform (experimentally ‘clogged’) screens would provide important information on the cleaning regimes that will have to accompany use of new screens. Finally, screen requirements of adult delta smelt should be determined over the range of springtime temperatures likely to be observed in the delta.

The apparent sensitivity of delta smelt to the salvage process makes research into entrainment avoidance and screening effectiveness of vital significance to large-scale decisions regarding smelt protection at the export facilities. CVPIA and CalFed are expected to invest very large sums of money into improving the performance of fish screens and the salvage process at the State and federal salvage sites. In addition to massive changes in facility structure, CalFed and CVPIA will propose actions including higher allowed pumping rates and various operational changes.

DFG and BOR are currently developing scientific investigations into the effectiveness of screening improvements for Delta smelt. These studies should continue in order to identify which, if any, accommodations for smelt need to be included in the new facilities and operations.

H_0 = Alterations in salvage facilities and process have no effect on the observed survival and health of entrained delta smelt.

CalFed has invested substantial sums of money into an Environmental Water account intended to reduce the likelihood of entrainment of endangered species, including Delta smelt. Hydrodynamic modeling of the effects of EWA operations would contribute substantially to evaluating the effectiveness of EWA as a tool to minimize the impacts of project operations on delta smelt entrainment. This problem is probably only approachable through various computer models of flow and particle movement in the delta, particularly DSM2.

H_0 = EWA actions taken to modify hydrodynamics in the delta have no effect on the residence time of particles in the delta or their likelihood of entrainment at the facilities.

Mesocosm dynamics of larval and early juvenile smelt entrainment

Estimating loss rates from salvage data requires measurement of mortality rates in Clifton Court Forebay and in the zone of influence of the federal and local diversion points. Several attempts have been performed to quantify the relationship between pumping rates and density of young smelt entrained. Although pre-screening losses occur at the Federal facilities, Clifton Court Forebay provides a much more tractable area for study. Construction of the Tracy Fish Test Facility and the proposed construction of one unit of screened intake into CCF will provide many more opportunities for study in the future.

In recent years, some casual experiments have been performed to see if higher pumping rates entrain higher densities of larval delta smelt. During these tests the radial gates have been kept closed so that the impacts of pumping are exerted upon the limited stock of smelt in the forebay. At present, interpretation of these results is confounded by numerous alternative explanations, none of which are entirely mutually exclusive. These alternative explanations reflect four different conceptual models and null hypotheses. Better understanding of the relationship between salvage and entrainment hinges on carefully designed studies that can differentiate among the hypotheses:

1. Higher velocities created by higher pumping rates take a larger portion of the local stock.

   If there is a normally distributed range of susceptibility to entrainment within the local stock, then low velocities take only the most susceptible individuals and higher velocities take more of the abundant individuals with average susceptibility. Higher pumping rates tend to occur during nighttime hours when electrical rates are low. However, lab studies of juvenile delta smelt show that their susceptibility to entrainment is much greater at night, so the anecdotal results are probably confounding the effects of export rate with fish behavior.

and/or

2. Larger areas of influence within the Forebay entrain fish from areas of higher densities. If, at low pumping rates, water tends to enter the Forebay through the gates and proceed to the export pumps, then a denser aggregation could remain in the slower circulating waters in other parts of the Forebay. This aggregation might arise from growth of fish that entered the Forebay before the individuals were large enough to be counted in the salvage, or fish may enter the forebay and behaviorally disperse into low flow. If densities of delta smelt can build up within the forebay to such an extent that they show functional responses to changes in pumping, it suggests that predation losses in the Forebay are small.

and/or

3. Higher velocities created by higher pumping rates increase the efficiency of the louvers in front of the salvage facilities. It is possible that increased turbulence at higher pumping rates increases the hydrodynamic barrier to smelt which are much smaller than the louver spacing even as adults. Careful assessments of fish density from salvage and fish density beyond the salvage facility could be used to test this hypothesis.

and/or

4. Higher velocities created by higher pumping rates reduce losses to predators residing in the Forebay by moving fish quickly through the system.

The peak of smelt spawning often coincides with the period of export reduction in support of the Vernalis Adaptive Management Program (VAMP). In recent years the four weeks of export reduction for VAMP have been expanded due to concerns about the high densities of larval smelt near the pumps. Under these conditions, daily pumping takes a small portion of the volume of water in Clifton Court Forebay, and considerable flexibility exists to alter the instantaneous pumping rate and measure changes in the rate of entrainment of delta smelt larvae. Carefully designed experiments using different pumping rates can investigate the "zone of influence" within the Forebay. Simultaneous intensive measures of larval densities throughout the Forebay and behind the louvers could put the numbers entrained into a mesocosmic view of 'population' effects. Development of a 3D hydrodynamic model of the Forebay is probably an essential component of these mesocosm studies. Expansion of such studies into the open waterways of the south delta could follow in later years.

The hypotheses to be tested include:

Zone of influence null hypothesis:
H_0 = Densities of smelt in water taken from the Forebay do not change at higher pumping rates

Density-driven impact null hypothesis:
H_0 = Larval densities in the Forebay are not perceptibly reduced by export of larvae.

Water velocity null hypothesis:
H_0 = Louver efficiency for smelt at the Skinner facility is not a function of water velocity through the facility

Predator null hypothesis:
H_0 = Smelt losses to predators in the Forebay do not change with water export rate.

Summary of recommendations and a sequence of IEP action

Meteorological conditions and the preliminary results from studies of multiple stressors on delta smelt suggest that 2003 provides an excellent window of opportunity to assess the impact of stressors on key aspects of the life cycle of delta smelt. Thus, IEP should ensure that adequate numbers of fish are collected and preserved appropriately so that studies of age and growth from otoliths and of contaminant and feeding effects to represent likely mechanisms of the impacts of starvation and chronic contaminant exposure can be evaluated. Similar studies should be planned for the likely different environmental conditions of 2004. Results from these two years should be used to develop more detailed studies into the most significant stressors identified in 2003-2004.

Work to assess basic biology and the studies of potential improvements in salvage efficiency will require large numbers of delta smelt which are currently produced in variable and uncertain numbers. While detailed study plans are developed for intensive studies to be implemented in 2004 and 2005, IEP should work in 2003 to help secure a reliable source of cultured delta smelt for the total number of expected uses. Ongoing studies in 2003 will likely use many of the cultured smelt currently available.

We have generally been unable to demonstrate an actual zone of influence of the pumps and to assess indirect mortality affects associated with the different export rates. Determination of how delta smelt abundance and distribution relate to export operations is crucial to management and protection of this fish. Field studies of the overall population have failed to answer this question so we recommend the development of intensive studies using the segment of the population captured within Clifton Court Forebay. In 2003, sampling regimes of predators and smelt within CCF should be developed and tested as pilot studies. Measurement of salvage changes in response to structured variations in pumping regimes should be designed and carried out. In 2004 and 2005 sampling in the Forebay and experimental pumping rates should be combined to address how different pumping rates affect salvage and densities of delta smelt in the vicinity of the pumps.

Finally, the IEP agencies that have collected most of the field data on delta smelt should review the data and develop guidelines for its use. Ideally, these data would be made publicly available on the DGF delta smelt website, along with associated information on metadata, frequently-asked-questions and previous studies in which the data have been used.

Appendix D:
A Suggested Strategy for Delta Smelt Research

A Suggested Strategy for Delta Smelt Research

DRAFT

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A Suggested Strategy for Delta Smelt Research

Need for a Delta Smelt Research Strategy

Delta smelt is listed under the California and federal Endangered Species Acts (Federal Register 58:12854, March 5, 1993). Consequently, formal consultations with the U.S. Fish and Wildlife Service (USFWS) are required for human activities that potentially affect delta smelt and their habitat. The purpose of consultation is to determine whether proposed activities jeopardize the continued existence of a listed species or destroy or adversely modify critical habitat. They also determine the extent of anticipated incidental take. Consultations have resulted in changes to human activities that are considered necessary to avoid jeopardy (i.e., reasonable and prudent alternatives) and constraints to minimize the impacts of incidental take (i.e., reasonable and prudent measures). Reasonable and prudent alternatives and measures have substantially increased the cost of specific human activities, especially the cost of providing water for municipal, industrial, and agricultural uses.

As a consequence of the status of delta smelt and other listed and sensitive species, and the resulting constraints on water supply, the CALFED Bay-Delta Program (CALFED) was formed in 1995 to restore ecological health and improve water management in the Bay-Delta system (CALFED 2000). CALFED developed goals and objectives that include:

- Improve and increase aquatic and terrestrial habitats and improve ecological functions in the Bay-Delta to support sustainable populations of diverse and valuable plant and animal species.

- Reduce the mismatch between Bay-Delta water supplies and current and projected beneficial uses depending on the Bay-Delta system.

- Achieve recovery of at-risk native species, including delta smelt.

As part of CALFED, the Environmental Water Account (EWA) has the following interrelated goals:

- Reduce conflicts between environmental needs and water project operation by providing water and flexibility.

- Better protection for fish and habitats at critical times by providing water in a flexible manner other than through strict requirements.

- Increase water supply reliability by allowing projects to meet environmental and water supply needs at the same time.

CALFED recognizes that relaxing constraints on water supply could require recovery of at-risk native species, including delta smelt. Substantial uncertainties exist relative to the magnitude of the effect of human activities on delta smelt and actions that may be required to protect and recover delta smelt. Research is necessary to address uncertainties and to help identify appropriate protective measures and recovery actions.

Without a strategy to guide and prioritize research, the USFWS, CALFED, and other agencies will have difficulty determining priorities relative to the actions and research that are likely to contribute most to delta smelt protection and recovery and, subsequently, lead to improved water supply management in the Bay-Delta system.

Foundation of a Strategy for Delta Smelt Research

A research strategy should lead to selection, funding, and implementation of research based on prioritization that considers causality, level of proof, and management cost (Figure 1). The first step in a strategy for prioritizing research is development of an explicit framework within which information about the ecosystem and the needs of the target species is gathered, organized, and analyzed (Lestelle et al. 1996). Figure 2 illustrates the framework to organize and evaluate environmental and species specific data. Beyond the recovery objectives and criteria in the Delta Native Fishes Recovery Plan (U.S. Fish and Wildlife Service 1996), a management strategy and its supporting framework has yet to be fully and explicitly developed for delta smelt. However, sufficient information is available to move forward the process of prioritizing delta smelt research.

Information about delta smelt habitat and environmental needs is organized by life stage (Table 1). Table 1 is an incomplete presentation of the available data; however, the information is an example of the defining environmental conditions for delta smelt habitat elements.

Causality

The strength of the connection between cause (e.g., changes in environmental conditions) and effect (e.g., population response) is causality. The primary drivers of causality are relationships between survival and habitat quality and quantity (e.g., rearing area, biological community, entrainment). The relationship between habitat elements and survival must be identified; and, to the extent practicable, the relationships should be stated as equations that allow quantification of the survival response to changes in environmental variables. Example survival relationships are identified in Table 2 and conceptual relationships between flow and survival are illustrated in Figures 3 and 4. Substantially more effort will be required to develop equations that estimate the survival response, quantifying the strength of the connection between cause and effect.

Although equations have not been developed to quantify the survival response, scientists concerned with delta smelt management have stated those relationships believed to substantially affect delta smelt abundance (U.S. Fish and Wildlife Service 1995 and 1996, CALFED EWA Report 2001). The statements of importance currently form the basis for assigning levels of causality. Survival relationships that appear to have minimal effect on species population abundance should receive a low causality level (i.e., 1 or 2). Survival relationships that measurably affect the population abundance of delta smelt should receive a high causality level (i.e., 3 or 4).

Level of Causality	**Definition**
1	Does not affect survival
2	May affect survival, but would not result in a measurable life stage response
3	Affects survival to the extent that life stage abundance would measurably change within a portion of the geographic range of the population; minimal measurable effect on overall life stage production and population abundance of spawning adults, especially over the long term
4	Affects survival to the extent that population abundance of spawning adults would measurably change over the long term

The level of causality for survival relationships identified in Table 2 is based on population effects implicit in relationships identified in various documents (U.S. Fish and Wildlife Service 1995 and 1996, CALFED EWA Report 2001). For example, the decline of delta smelt abundance has been attributed to low outflows (i.e., as a result of reservoir storage and water supply diversions) that maintain fish larvae and juveniles in the deep and narrow channels of the Delta (U.S. Fish and Wildlife Service 1996). The location of rearing habitat in response to water supply activities is believed to reduce survival to a level that substantially affects abundance of spawning adults. The relationship between rearing habitat location and survival, therefore, would be assigned a causality level of 4.

Level of Proof

Level of proof indicates the uncertainty assigned to scientific support of cause and effect. The level of proof ranges from speculative relationships (i.e., high uncertainty) to those relationships that are thoroughly established, generally accepted, and supported by peer-reviewed evidence (i.e., low uncertainty). The level of proof is based on the literature that supports the survival relationships identified in Table 2. Level of proof is assigned to all relationships regardless of causality (Figure 1). Level of causality is based on available information. A low level of causality may reflect inadequate information about the relationship rather than actual understanding of the population response.

Level of Proof	Definition
1	Cause and effect relationships are thoroughly established, generally accepted, and supported by peer-reviewed evidence. In general, the magnitude of change in effect can be predicted from a given magnitude change in cause.
2	Evidence from experiments and observations clearly supports the theoretical relationship for cause and effect. In general, the direction of change in effect can be predicted from a given magnitude change in cause.
3	Some evidence from experiments and observation supports the theoretical relationship for cause and effect. Neither the direction nor magnitude of change in effect can reliably be predicted from a given magnitude change in cause.
4	Speculative, little empirical support

Adapted from Mobrand, Inc. 2001. Ecosystem Diagnosis and Treatment. How the rules work: translating level 2 environmental correlates into level 3 life stage survival factors for chinook salmon.

Preliminary evaluation of delta smelt literature resulted in levels 3 or 4 assigned to the survival relationships (Table 2), indicating relatively weak support and the need for research.

Management Cost

Management cost is the current and expected future cost for implementation of species management actions. For delta smelt and other listed species, species management actions are implemented to avoid, minimize, or mitigate the effects of human activities (e.g., water storage and diversion, waste water discharge, agricultural activities, dredging, flood protection activities) on species survival. Management actions include operations constraints (e.g., restricted timing, duration, frequency, and magnitude), facilities to protect and support fish population production (e.g., fish screens, fish ladders, hatcheries), and restoration-related activities (e.g., Environmental Water Account, habitat creation and maintenance, non-native species management).

The management cost is the total for all species management actions that are implemented to increase survival through change in a specific habitat element (e.g., rearing habitat area, entrainment, water quality). Management cost may address multiple habitat elements that increase survival for multiple species and could therefore be considered independently or proportionately (i.e., related to the proportional benefit to each habitat element and species).

Level of Management Cost	Definition
1	Cost is less than $1,000,000 in one time expenditures
2	Cost is less than $10,000,000 over a 10-year period
3	Cost is less than $100,000,000 over a 10-year period
4	Cost exceeds $100,000,000 over a 10-year period

The level of management cost assigned in Table 2 is currently based on professional judgement and should be considered as examples only. As with other elements involved in prioritizing research, substantially more effort is required to increase the accuracy of the cost estimated for implementation of current and future species management actions. However, the levels in most cases are not unrealistic. For example EWA expenditures in water year 2000-2001 resulted in the purchase of several hundred thousand acre-feet of water, a cost of tens-of-millions of dollars.

For the purposes of identifying research priorities, research is not included in the cost of the species management actions. However, management cost does include the expense of tracking compliance with applicable permit requirements, such as monitoring salvage at the CVP and SWP fish facilities, physical performance of fish screens, and conformance with operations criteria and design specifications.

Research Priorities

Based on the levels of causality and proof assigned in Table 2, 12 high priority survival relationships were identified (Table 3). Hypothetical mechanisms (i.e., statements of hypotheses that could be the focus of delta smelt research) are identified for most of the survival relationships. All of the priority relationships and most of the hypothetical mechanisms are dependent to some degree on net channel flow in the Delta. Research should focus on those hypothetical mechanisms that address the highest flow-related management cost, including EWA expenditures and constraints on exports. The highest priority research areas would include:

- The effect of flow on the movement and distribution of spawning adult delta smelt (mechanism 5 in Table 3).
- The effect of flow on travel time for larval and early juvenile delta smelt (mechanism 8 in Table 3).
- The effect of net flow direction on movement and subsequent entrainment of larval and early juvenile delta smelt (mechanism 12 in Table 3).

Figure 1. A Strategy for Delta Smelt Research

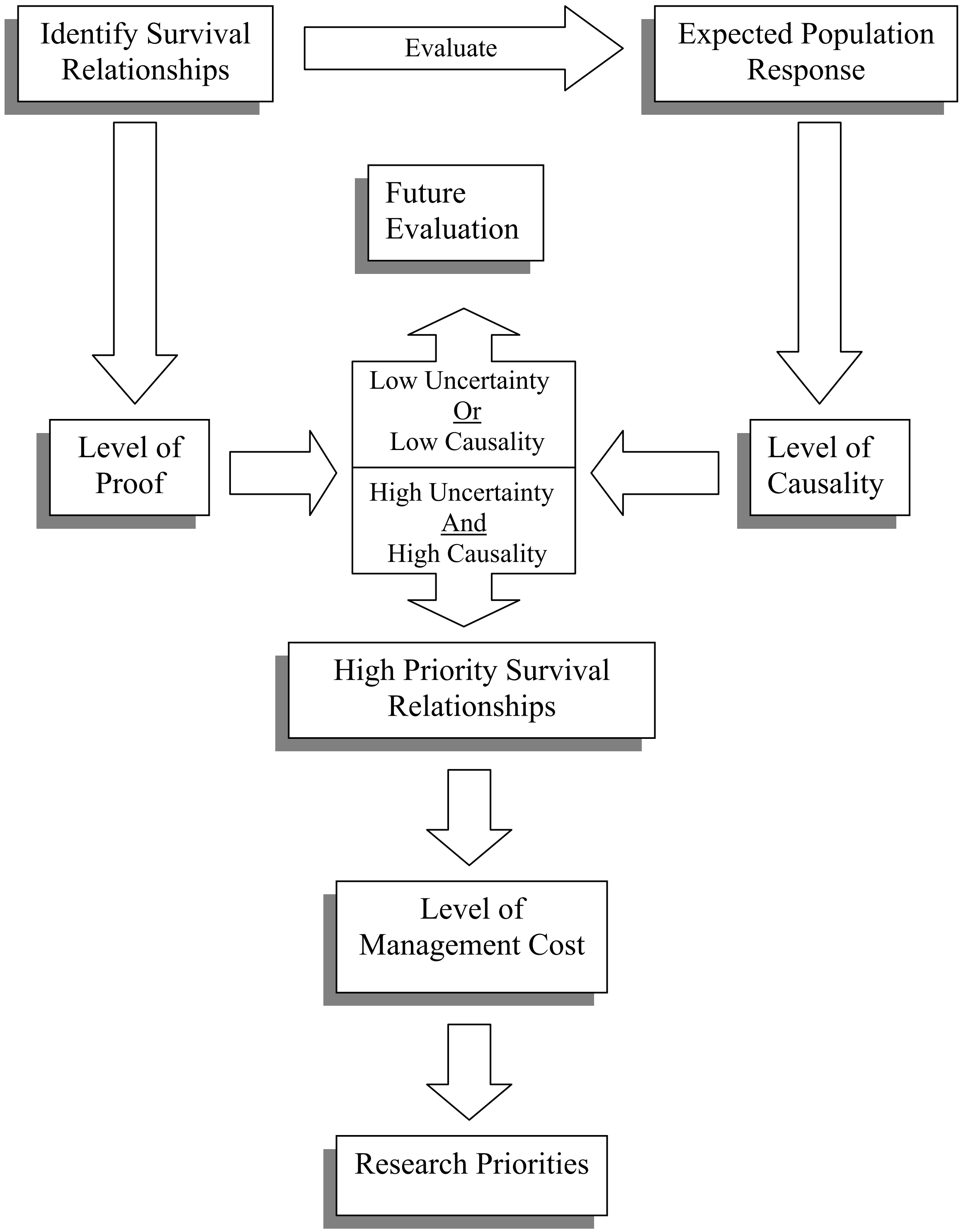
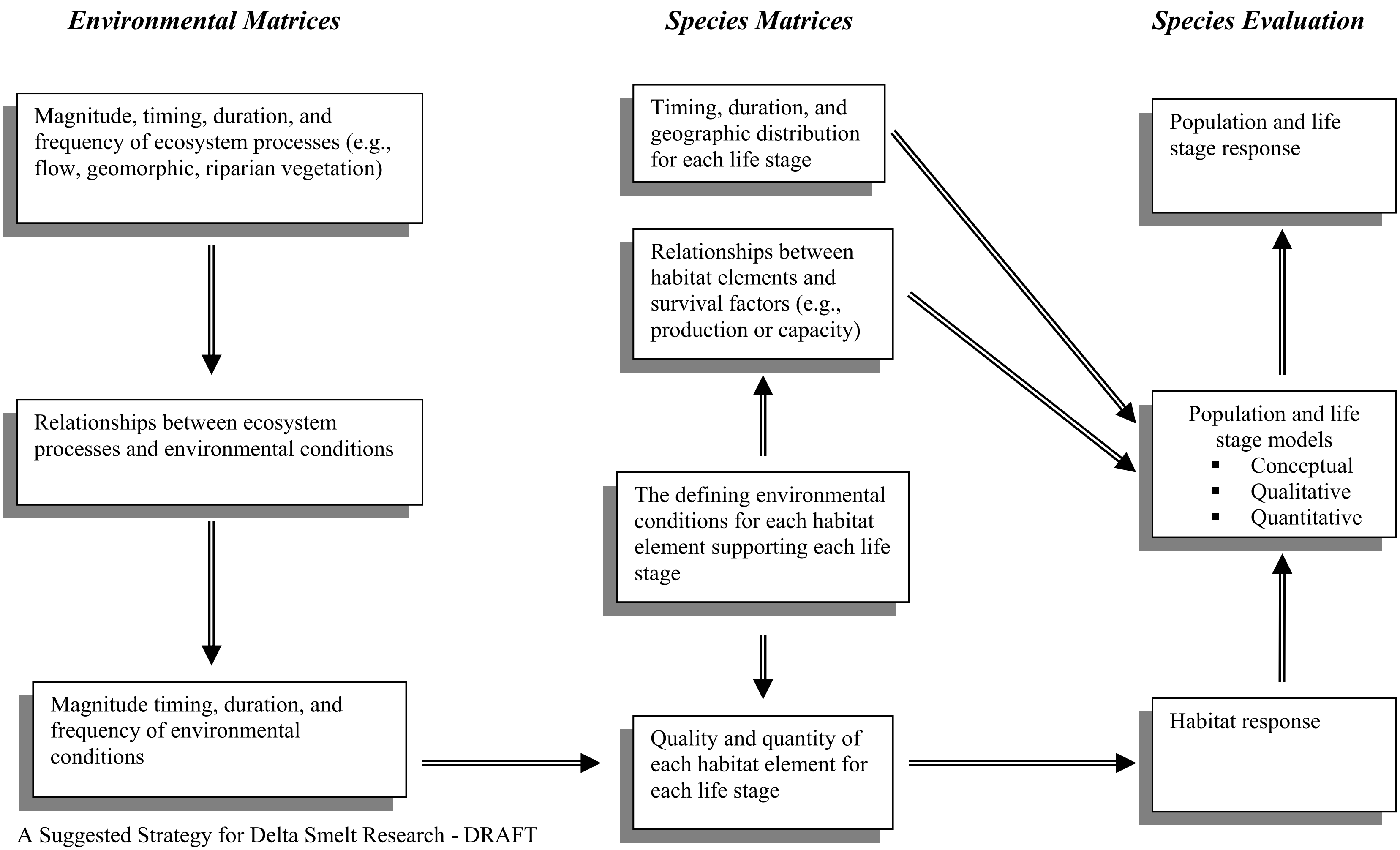


Figure 2. Fish Species Evaluation Overview



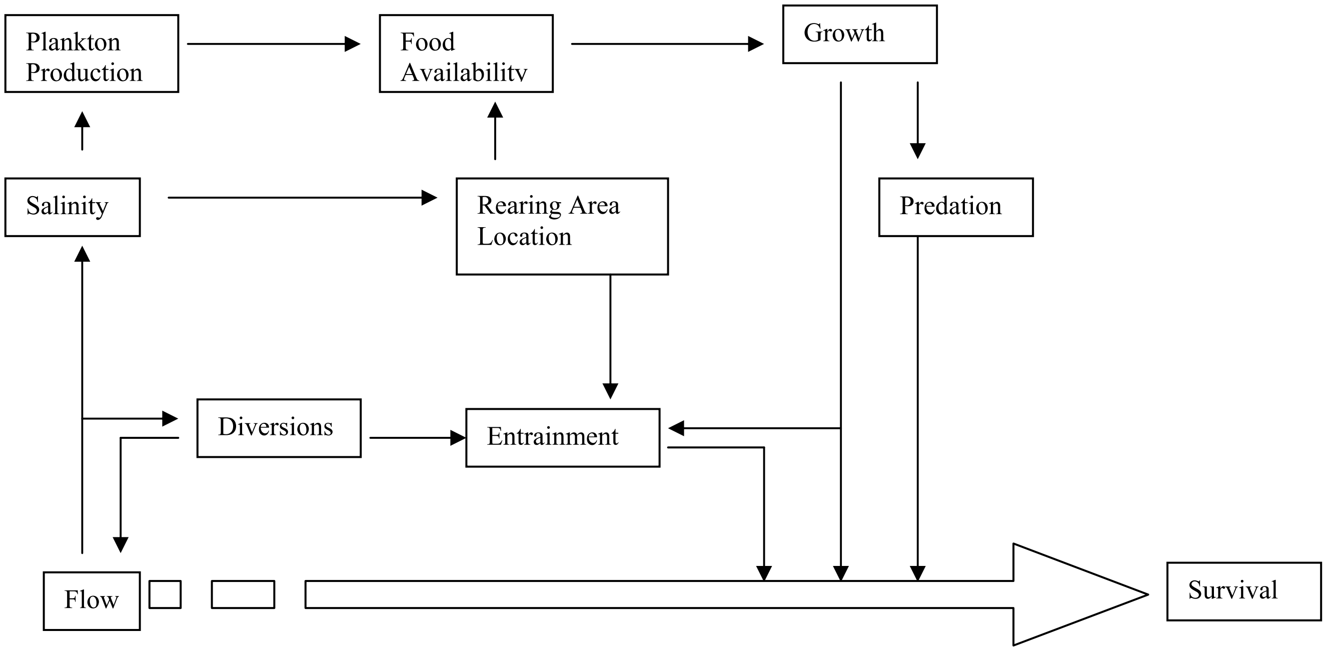


Figure 3. Conceptual Representation of Flow Related Effects on Survival during Estuarine Rearing for Juvenile and Adult Delta Smelt

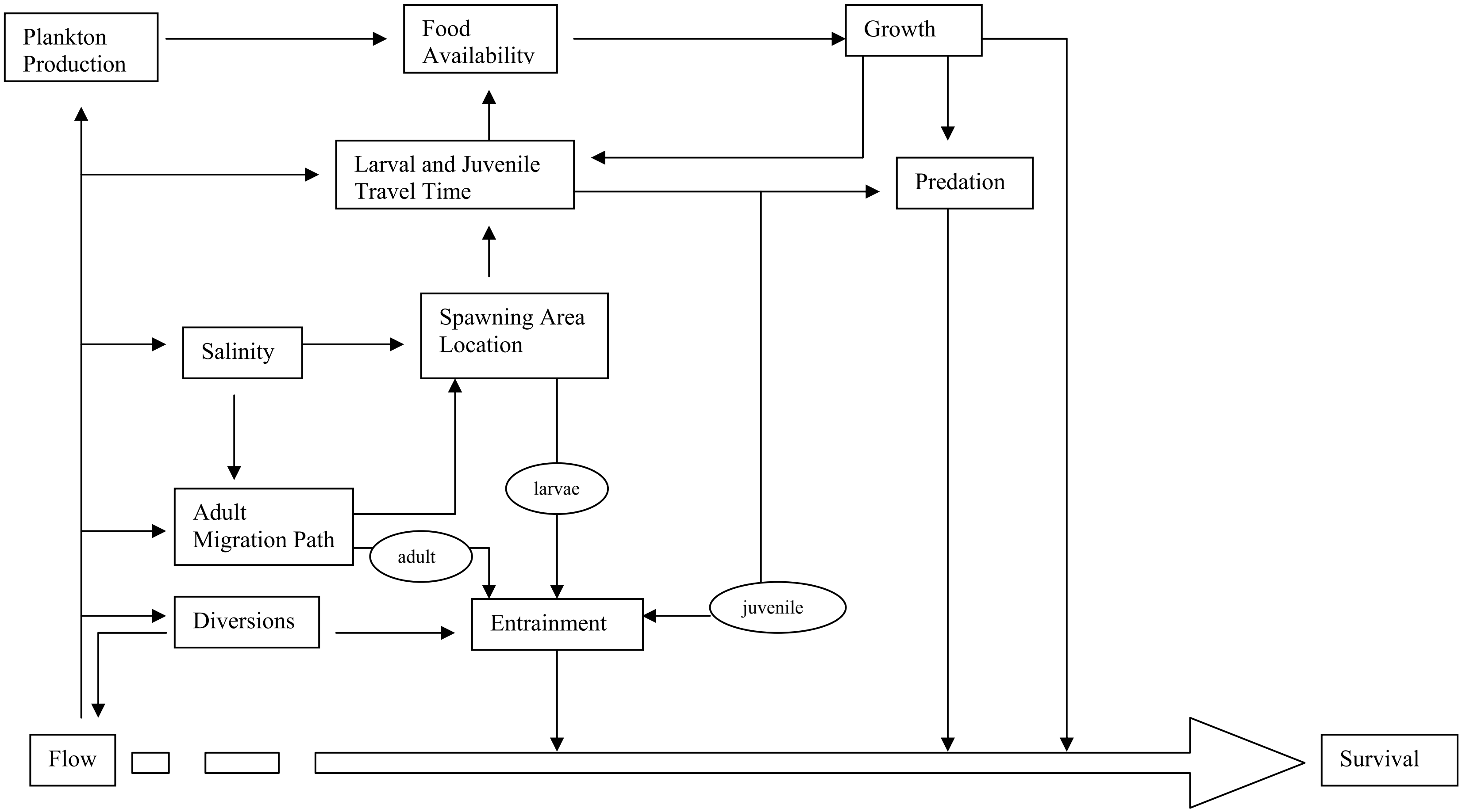


Figure 4. Conceptual Representation of Flow-Related Effects on Survival during Adult Migration and Larval and Juvenile Movement

Table 1. Delta Smelt Habitat

Life Stage	*Habitat Element*	*Environmental Conditions*	*Description*
Estuarine Rearing	Rearing area	Depth Velocity Channel pattern and geometry Salinity	Rearing area may encompass the lower reaches of the Sacramento River below Isleton, the San Joaquin River below Mossdale, through the Delta and into Suisun Bay. Rearing area for juvenile and adult delta smelt is defined as the area within the salinity range of 2 ppt to 7 ppt, although they can withstand fresh water and salinity up to 19 ppt (Moyle 2002). The rearing area available depends on the location of the appropriate salinity range. During years of average and high outflow delta smelt may concentrate anywhere from the Sacramento River around Decker Island to Suisun Bay (Moyle 2002). Although the geographic distribution is a function of salinity between 2ppt and 7 ppt (Moyle 2002), geographic distribution may not always be a function of outflow and the 2 ppt isohaline position (X2). Outflow and the position of the 2-ppt isohaline may account only for about 25% of the annual variation in abundance indices for delta smelt (CDWR and US Bureau of Reclamation 1994). Delta smelt survival rates are generally highest when salinity of 2 ppt is in the shallow areas of Suisun Bay during the preceding spring, however the relationship has not been consistent over time (Moyle 2002). Delta smelt prefer depths less than 4 meters that have relatively low velocities (Moyle et al. 1992).

Table 1, continued.

Life Stage	*Habitat Element*	*Environmental Conditions*	*Description*
	Water quality	Water Temperature	Delta smelt distribution appears not to be limited by temperature (Moyle et al. 2002). Successful estuarine rearing has been observed from 6°C to 23°C (Moyle et al 1992. Delta smelt can be found at water temperatures as high as 28 C. Swanson and Cech (1995) found that delta smelt lethal temperature is 29 C.
		Salinity	Delta smelt can withstand freshwater and salinity exceeding 19 ppt (Moyle 2002).
		Turbidity	Delta smelt remain in the water column and hide from predators in turbid water (Moyle 2002). Water transparency may have the greatest effect on year-class strength during the first half of each year when DFG believes year class strength is set (Stevens et al 1990 in USFWS and Bureau of Reclamation 1994).
	Contaminants	Metals Nutrients Pesticides Parasitoids (e.g., viruses, bacteria, fungi)	The effects of metals and pesticides on delta smelt and their food supply are not well understood. Planktonic organisms may be affected by high concentration of pesticides occasionally depleting delta smelt food sources (US Fish and Wildlife Service 1996). Delta smelt survival rates may have been lowered in the past due to the frequent presence of parasites such as a tapeworms. However, there is not direct evidence of population decline due to parasites (Moyle 2002).

Table 1, continued.

Life Stage	*Habitat Element*	*Environmental Conditions*	*Description*
	Biological Community	Predators Competitors Disease and parasites Food	Predators such as striped bass, largemouth bass and catfish may have an effect on delta smelt. However, the extent at which these predators may affect delta smelt populations is unknown. In addition, competitor species such as threadfin shad and wakasagi may also have an effect on delta smelt populations by competing for food sources and rearing habitat. When the mixing zone is Suisun Bay, the system is more productive, so more zooplankton is available as food (Moyle et al. 1992). The coincidence of areas of high food production and delta smelt rearing location is likely important to survival. Changes in food species may also affect delta smelt. Non-native zooplankton species are more difficult for small smelt to capture increasing the likelihood of larval starvation (Moyle et al. 2002).

Table 1, continued.

Life Stage	*Habitat Element*	*Environmental Conditions*	*Description*
	Entrainment	Diversion: volume, frequency, duration, timing; approach velocity; position, including depth and distance from shore; location relative to occupied delta smelt habitat Tidal amplitude Fish screens: screen opening, approach velocity, sweeping velocity Predator species habitat	Delta smelt may be entrained with flow diverted from the river. The probability of entrainment and subsequent mortality is a function of the size of the diversion, the location of the diversion, the behavior of the fish, and other factors, such as fish screens, presence of predatory species, and water temperature. Approach velocities of 0.2 feet per second are assumed to minimize stress and protect fish from entrainment. The velocity at which delta smelt changes gaits, between 10 and 15 cm/s appears to be very stressful (Swanson et al. 1996).
Adult Migration	Continuity/False Pathways	Net flow pattern Barriers	Net channel flows and barriers may attract adult delta smelt along pathways and to spawning habitat where survival and future life stage production is marginal.
	Water Quality	Water temperature Dissolved oxygen Turbidity	Well oxygenated waters (dissolved oxygen concentrations >5 mg/l) and water temperature ranging from 6°C to 23°C is assumed to provide adequate conditions for adult migration.
	Contaminants[1]	Metals Nutrients Pesticides Salt Parasitoids (e.g., viruses, bacteria, fungi)	The effects of metals and pesticides on adult delta smelt and their food supply are not well understood. However, adult delta smelt are short lived, thus bioaccumulation effects are less likely to occur.

Table 1, continued.

Life Stage	*Habitat Element*	*Environmental Conditions*	*Description*
	Biological Community	Predators Competitors Disease and parasites	See previous discussion on biological community
	Entrainment	Diversion: volume, frequency, duration, timing; approach velocity; position, including depth and distance from shore; location relative to occupied delta smelt habitat Fish screens: screen opening, approach velocity, sweeping velocity Predator species habitat	Delta smelt may be entrained with flow diverted from the river. The probability of entrainment and subsequent mortality is a function of the size of the diversion, the location of the diversion, the behavior of the fish, and other factors, such as fish screens, presence of predatory species, and water temperature. Approach velocities of 0.2 feet per second are assumed to minimize stress and protect fish from entrainment. Salvage data indicate that at the Tracy Pumping Plant entrainment adult delta smelt occur during their spawning migration from December through April (USFWS and Bureau of Reclamation 1994).
Spawning	Spawning area	Substrate (e.g., gravel, cobble, rock, woody material, vegetation) Channel geometry Depth Velocity Salinity	Delta smelt spawn in freshwater at low tide on aquatic plants, submerged and inshore plants over sandy and hard bottom substrates of sloughs and shallow edges of channels in the upper Delta and Sacramento River above Rio Vista (Wang 1986, Moyle 2002).
	Water quality	Water temperature Dissolved oxygen Salinity Suspended sediment	Successful spawning occurs in fresh turbid water within a temperature of 7^{o}C and 22^{o}C (U.S. Fish and Wildlife Service 1996) with most spawning taking place between 7C and 15C and in well-oxygenated water (Moyle 2002).

Table 1, continued.

Life Stage	*Habitat Element*	*Environmental Conditions*	*Description*
	Biological Community	Predators Competitors Hybridization Disease and parasites	Inland silverside and yellowfin goby may prey on delta smelt eggs and larvae (U.S. Fish and Wildlife Service 1996). Introduced planktivores such as threadfin shad may compete for food resources. However, these interactions have not been studied (U.S. Fish and Wildlife Service 1996). Effects of disease and parasites on delta spawning have not been studied.
Incubation	Water quality	Water temperature Salinity Suspended sediment Dissolved oxygen	Larval delta smelt have been captured in freshwater that ranges between 7-15C, Moyle (2002) suggest that survival rates decrease as temperature increases beyond 18C.
	Contaminants	Metals Nutrients Pesticides Salt Parasitoids (e.g., viruses, bacteria, fungi)	The effects of metals and pesticides on adult delta smelt and their food supply are not well understood. However, larvae and juvenile delta smelt are more likely to be affected by contaminants during the early stages of development.
	Biological Community	Predators Competitors Disease and parasites	Inland silverside and yellowfin goby may prey on delta smelt eggs and larvae (U.S. Fish and Wildlife Service 1996). Introduced planktivores such as threadfin shad may compete for food resources. However, these interactions have not been studied (U.S. Fish and Wildlife Service 1996). Effects of disease and parasites on delta spawning have not been studied

Table 1, continued.

Life Stage	***Habitat Element***	***Environmental Conditions***	***Description***
Larval and Early Juvenile Rearing and Migration	Rearing area	Depth Velocity Channel pattern and geometry Salinity	Larvae are found near the surface of water column in high currents (Sweetnam 1998, Moyle 2002) see estuarine rearing
	Continuity	Tidal flow Net flow pattern Flow divisions Barriers	Larval and early juvenile delta smelt are transported by currents that flow downstream into the upper end of the mixing zone of estuary where incoming saltwater mixes with out-flowing freshwater (Moyle et al. 1992). Moyle et al. (1992 in U.S. Fish and Wildlife Service and Bureau of Reclamation 1994) propose that reverse flows may draw young fish to the export pumps from spawning and nursery areas in the central and western Delta. Preliminary results from DWR Particle tracking model simulations suggest that the effect of high flows on the transport process diminish rapidly as the flow approaches the western Delta. It also suggests that particles in the interior Delta were entrained by CVP and SWP pumps and agricultural diversions despite the high positive index of net flow in the San Joaquin River. Model results based on the assumption that delta smelt are neutrally buoyant may not accurately reflect the effect of net flow on transport and entrainment of young fish in the Delta (U.S. Fish and Wildlife Service and Bureau of Reclamation 1994).
	Water quality	Dissolved oxygen Water temperature Salinity Turbidity	Well-oxygenated water with temperature less than 22 °C and salinities of 2 ppt or less provide optimal conditions for larvae and early juvenile rearing. Delta smelt can withstand temperature conditions as high as 28 °C. 29 °C is delta smelt lethal limit (Swanson and Cech 1995 and Swanson et al 2000 in Moyle 2002). Information on turbidity is lacking.

Table 1, continued.

Life Stage	*Habitat Element*	*Environmental Conditions*	*Description*
	Contaminants[1]	Metals Nutrients Pesticides Salt Parasitoids (e.g., viruses, bacteria, fungi)	The effects of metals and pesticides on larval delta smelt and their food supply are not well understood. Planktonic organisms may be affected by high concentration of pesticides occasionally, thus depleting delta smelt food sources (US Fish and Wildlife Service 1996).
	Biological Community	Predators Competitors Disease and parasites Food	Although it is not certain that predation, competition disease and parasites have caused delta smelt populations to decline, predation by inland silversides especially during low-outflow years may have an effect on delta smelt population (Bennett 1998). Changes in food sources may also have an effect on delta smelt. Non-native zooplankton species are more difficult for small smelt to capture increasing the likelihood of larval starvation (Moyle et al. 2002).

Table 1, continued.

Life Stage	*Habitat Element*	*Environmental Conditions*	*Description*
	Entrainment	Diversion: volume, frequency, duration, timing; approach velocity; position, including depth and distance from shore; location relative to occupied delta smelt habitat Tidal amplitude Fish screens: screen opening, approach velocity, sweeping velocity Predator species habitat	As discussed above under continuity, Delta smelt may be entrained with flow diverted from the Delta. The probability of entrainment and subsequent mortality is a function of the size of the diversion, the location of the diversion, the behavior of the fish, and other factors, such as fish screens, presence of predatory species, and water temperature. Approach velocities of 0.2 feet per second are assumed to minimize stress and protect fish from entrainment in diversions with sufficient sweeping velocity.

Table 2. Delta Smelt Survival Relationships and the Associated Level of Causality, Proof, Management Cost, and Research Cost

Life Stage	***Habitat Element***	***Level of Causality***	***Level of Proof***	***Level of Management Cost***	***Potential Survival Relationship***
Estuarine Rearing	Rearing area	4	3	3	Survival = f(rearing area location) – higher survival or abundance occurs when 2ppt is in Suisun Bay; a function of flow
	Water quality	1	3		
	Contaminants	2	4		Survival = f(contaminant concentration)
	Biological Community	4	3	3	a) Survival = f(food density, coincidence of rearing area and high food density) – higher food production occurs when 2 ppt is in Suisun Bay; a function of flow; non-native zooplankton may be a factor. b) Survival = f(predation and competition by non-native species)
	Entrainment	3	3	2	Survival = f(diversion timing, location, and volume; fish screen efficiency; coincidence of rearing area and diversion location) – higher entrainment occurs when diversion and rearing area location overlap; a function of flow and diversion operations
Adult Migration	Continuity/False Pathways	4	4	3	Survival = f(migration pattern) – migration pattern and spawning location is determined by Delta flow; entrainment is higher for adults attracted to the South Delta and for larvae from South Delta spawning habitat
	Water Quality	1	3		
	Contaminants	2	4		Survival = f(contaminant concentration)
	Biological Community	2	4		Survival = f(predation by non-native species)

Table 2, continued.

Life Stage	*Habitat Element*	*Level of Causality*	*Level of Proof*	*Level of Management Cost*	*Potential Survival Relationship*
	Entrainment	4	3	3	Survival = f(diversion timing, location, and volume; fish screen efficiency; coincidence of migration path and diversion location) – higher entrainment occurs when diversion and migration overlap; a function of Delta inflow and diversion operations
Spawning	Spawning area	2	3		
	Water quality	1	3		
	Biological Community	2	3		Survival = f(predation by non-native species)
Incubation	Water quality	1	3		
	Contaminants	2	4		Survival = f(contaminant concentration)
	Biological Community	4	3	1	Survival = f(predation by non-native species)
Larval and Early Juvenile Rearing and Migration	Rearing area	2	4		Transport to estuarine rearing area (see continuity) is likely more critical than fresh water rearing area
	Continuity	4	3	3	Survival = f(travel time) – travel time increases at lower net flow; a function of Delta inflow, diversion operations, flow pattern, flow divisions, tidal flow; potential close relationship to entrainment
	Water quality	1	3		
	Contaminants	3	3	?	Survival = f(contaminant concentration)

Table 2, continued.

Life Stage	***Habitat Element***	***Level of Causality***	***Level of Proof***	***Level of Management Cost***	***Potential Survival Relationship***
	Biological Community	4	3	?	a) Survival = f(food density, coincidence of rearing area and high food density) – higher food production may be associated with Delta inflow; non-native zooplankton may be a factor. b) Survival = f(predation and competition by non-native species)
	Entrainment	4	3	3	Survival = f(diversion timing, location, and volume; coincidence of spawning area and sphere of influence for diversions) – entrainment increases with increasing sphere of influence for diversions; a function of flow and diversion operations

Table 3. High Priority Survival Relationships for Delta Smelt and the Hypothetical Mechanisms Affecting Survival

Life Stage	***Habitat Element***	***Hypothetical Mechanisms***
Estuarine Rearing	Rearing area	1) Greater rearing area results in higher survival. Rearing area is a function of location that is dependent on net Delta outflow and its effect on salinity (i.e., X2).
	Biological Community	2) Higher prey density measurably increases smelt survival and life stage production. (a) Higher prey density occurs in Suisun Bay. Positioning estuarine rearing habitat in Suisun Bay increases food availability for delta smelt (related to mechanism 1). (b) Prey density and food availability for delta smelt increases following higher Delta outflow regardless of the location of estuarine rearing habitat. (c) Prey density within the zooplankton community is reduced relative to historic conditions because non-native zooplankton have become established and non-native fish and invertebrates compete with delta smelt for limited zooplankton resources. 3) Predation by non-native species measurably reduces smelt survival and life stage production. (a) Predation by non-native species is facilitated by location of rearing habitat in the Delta channels rather than Suisun Bay. (b) Greater rearing area reduces density and reduces predation rates by non-native species. Smaller rearing area increases vulnerability to predation (related to mechanism 1). (c) Slower growth rates (related to mechanism 2) result in higher predation rates.
	Entrainment	4) Entrainment of adult and juvenile delta smelt in diversions measurably decreases survival and life stage production. (a) Positioning rearing habitat upstream of Chipps Island repeatedly exposes delta smelt to entrainment in power plant and agricultural diversions (related to mechanism 1). (b) Fish screens with approach velocities of <0.2 feet/second can measurably reduce entrainment and increase survival.

Table 3, continued.

Life Stage	*Habitat Element*	*Hypothetical Mechanisms*
Adult Migration	Continuity/false pathways	5) Survival and future life stage production is measurably affected by migration pathway and spawning habitat location. The South Delta currently provides marginal migration and spawning habitat (related to mechanisms 6, 7, 8, 10, 11, and 12). (a) Exports draw Sacramento River flow into the South Delta and the presence of Sacramento River flow attracts adult delta smelt. (b) Adult delta smelt return to natal spawning areas. (c) Adult delta smelt are drawn to spawning areas by unknown environmental factors.
	Entrainment	6) Entrainment of adult delta smelt in diversions measurably decreases life stage and ultimately spawner abundance. (a) Occurrence of adult delta smelt in the South Delta increases vulnerability to entrainment. (b) Fish screens with approach velocities <0.2 feet/second can measurably reduce entrainment and increase survival and future life stage production. (c) Salvage at Banks and Tracy increases survival of entrained delta smelt and measurably increases life stage abundance. (d) Predation on delta smelt in Clifton Court Forebay measurably reduces salvage efficacy.
Incubation	Biological Community	7) Predation by non-native species on eggs in spawning habitat limits delta smelt production. (a) Predator abundance and predation is higher in the South Delta.
Larval and Early Juvenile Rearing and Migration	Continuity	8) Longer travel time to estuary rearing habitat results in lower survival (related to mechanisms 10, 11, and 12). (a) Larval smelt move passively with flow and travel time is dependent on net channel flow. Lower net downstream flow increases travel time to estuarine rearing habitat. (b) Larval smelt actively maintain their location and movement toward estuarine rearing habitat (i.e., X2) is dependent on growth rate and developmental stage. (c) Larval and early juvenile smelt actively move toward estuarine rearing habitat. Travel time is dependent on the distance between spawning habitat and estuarine rearing habitat.

Table 3, continued.

Life Stage	*Habitat Element*	*Hypothetical Mechanisms*
	Contaminants	9) Contaminants reduce the survival of delta smelt larvae and early juveniles (related to mechanisms 10 and 11). (a) Contaminants reduce growth through direct effects on delta smelt. (b) Contaminants increase susceptibility to disease, parasites, and predation.
	Biological Community	10) Higher prey density in freshwater rearing habitat measurably increases smelt survival and life stage production. Lower prey density results in slower growth and development. (a) Prey density and food availability for larval and early juvenile delta smelt in the Delta increases following higher Delta inflow. (b) High exports, relative to Delta inflow, reduce prey density. (c) Prey density is in response to change in the zooplankton community caused by introduction of non-native competitors and predators. (d) Prey density is in response to contaminants (see contaminants in mechanism 9) 11) Predation by non-native species measurably reduces smelt survival and life stage production (related to mechanisms 8 and 9). (a) Predation may be facilitated by longer travel time (mechanism 8). (b) Predation may be facilitated by slower growth rates (mechanism 10). (c) Predation may be facilitated by low turbidity that is potentially related to Delta inflow and diversions or to changes in the biological community (e.g. *Melosira* spp.).

Table 3, continued.

Life Stage	***Habitat Element***	***Hypothetical Mechanisms***
	Entrainment	12) Entrainment of larval and early juvenile delta smelt measurably reduces survival and life stage production. (a) Larval delta smelt move passively and entrainment fraction is dependent on net channel flows between spawning habitat and estuarine rearing habitat (related to mechanisms 5 and 8). Higher net channel flow toward the export pumps increases entrainment fraction. (b) Larval and juvenile delta smelt actively move with net flow. Fish exposed to net flow toward the export pumps are ultimately entrained in the facilities (related to mechanism 5 and 8). (c) Larval and juvenile smelt actively move toward estuarine rearing habitat and cue on some currently unknown factor (e.g., tidal cue, salinity and other chemical gradients). Entrainment is a function of the proximity of the diversion points to spawning habitat and travel time (related to mechanisms 5 and 8). (e) Fish screens with approach velocities <0.2 feet/second can measurably reduce entrainment and increase survival and future life stage production. (f) Salvage at Banks and Tracy increases survival of entrained delta smelt and measurably increases life stage abundance. (g) Predation on delta smelt in Clifton Court Forebay measurably reduces salvage efficacy (related to (e) and mechanism 11).